308

DETERIORATION OF ROUGH RICE AS MEASURED BY CARBON DIOXIDE PRODUCTION

by

AMIHARDJONO SUKAEDI

B.S. Fakultas Tehnologi Pertanian Universitas Gajah Mada Indonesia

1967

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1979

Approved by :

Paul A Seib

Major Professor

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

APPENDIX

LIST OF TABLES

APPENDIX D
LIST OF FIGURES

INTRODUCTION

The purpose of drying is to preserve agricultural products. In the drying process moisture is removed to prevent the development of a favorable environment for the growth of molds and insects that normally cause spoilage (1).

Rice is harvested at a moisture content between 18 and 22% (23). Therefore, it needs to be dried before storage.

Grain drying systems are classified as heated-air or fast and unheated-air or slow systems (1). Fast drying is accomplished by high temperature and requires more energy. Slow drying or in-storage drying is more economical with less energy required, but the time to complete the drying process is longer. Biological activity which may result in grain deterioration occurs during slow drying, thus the drying time may be a problem in the slow drying systems.

Grain deterioration is related to respiration of the grain itself and of the accompanying microorganisms (25). Carbon dioxide is the product of this respiration. Since the evolution of carbon dioxide can be measured readily, the measurement of carbon dioxide is used as index of deterioration (23).

Temperature, moisture content and time are variables associated with grain drying and grain deterioration. The carbon dioxide produced by fungi, and to a lesser extent, by the kernels, are related to those variables. Furthermore, Saul and Steele (25) reported CO_2 evolved can be correlated to dry matter loss of the kernels.

The object of this investigation was to study the carbon

dioxide evolved from rough rice stored at various temperatures, moisture contents and periods of time. From that data, a regression equation showing the quantitative relationship between dry matter loss (CO_2 evolved) and the variables of temperature, moisture content and time has been derived. That equation can be used to predict when stored rough rice will reach a given level of dry matter loss. In addition, the samples of rough rice were also graded to determine if dry matter loss could be used to predict rice quality.

REVIEW OF LITERATURE

GRAIN DRYING SYSTEM

The major objective in drying grain is to reduce the moisture content so that spoilage will not occur. Processes used to dry grain for storage are divided into two broad categories : those that dry grain in a stationary batch, and those that dry grain as it flows continuously in equipment (1).

Batch drying systems are classified as unheated-air and heated-air systems. In some ways classifying them as fast (heated-air) and slow (unheated-air) drying systems is more logical. A heater to increase the temperature of the air may be a part of the heated-air drying systems. Natural air is used in the unheated-air drying systems with a fan running continuously. The work done here simulates the unheated batch drying system.

Hukill (10) described static grain drying as "air forced through a deep bed of grain". In his description of the drying process, a layer of grain where drying occurs is called the drying zone. The drying zone forms where the air enters, and it progresses through the grain in the direction of air movement until drying is complete. Grain is still at its initial moisture content above the drying zone.

MAXIMUM DRYING TIME

When grain is harvested at a high moisture content, it will remain wet and susceptible to spoilage until the static grain drying process is practically completed for the entire bulk. The problem then is how long can wet grain be held under the

conditions found downstream from the drying zone before spoilage occurs?

Foster (6) suggested the possibility of a more energy-efficient grain drying system by decreasing the airflow rate and taking longer to dry the grain. He points out that doubling the rate of airflow from 2 to 4 cfm per bu (2.2 to 4.4 cu m per min per metric ton, based on 60 lb per bu) requires a six-fold increase in power consumption. However, since biological activity is present during grain drying and will result in grain spoilage, the maximum drying time is limited by the final quality of the grain desired. Using a deterioration index based on viability, fat acidity and commercial damage, Foster (6) concluded the minimum airflow rate for drying grain with unheated-air is largely dependent on the limit of grain deterioration that is acceptable. For Indiana conditions, the minimum airflow for drying wheat from 20% to 15.5% moisture without serious deterioration appears to be about 2 cfm per bu. For shelled corn, 3 cfm per bu appears to be adequate to dry from 25 to 15.5% moisture in moderate fall weather.

In 1958 Saul and Lind (18) concluded the corn that appeared to be in good condition after mechanical drying lost less than one percent of the initial dry matter during the drying period. They plotted their data to show the relationship between dry matter lost from shelled corn and drying time at four levels of moisture content and 77°F. Applying the 1% dry matter loss they concluded from the drying curve the maximum drying time is 12 to 14 days for the grain of

high initial water content (28 and 25%) and 30 days for the grain of lower initial water content (22 and 19%) at 77°F.

RESPIRATORY PROCESS

Under aerobic condition, the complete combustion of a hexose is represented by the following equation

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 667.2 \text{ Cal}$$

From this equation 10 g loss of pure carbohydrate (dry matter of the grain) is accompanied by the evolution of 14.7 g of carbon dioxide.

The respiratory process of mold growth is similar to that of grain itself. The combustion of carbohydrate is representative of what occurs in both grain and mold respiration.

In 1953 Hummel et al (11) reported their results of an experiment with a western white wheat free of molds. The wheats were sterilized by immersion in 1% sodium hypochlorite at room temperature. Furthermore, the sterilized grains were conditioned to 15-31% moisture using 1% sodium hypochlorite. The sterilization treatment did not affect the viability of the kernels, since 95% still germinated after treatment. The authors found that the respiratory rates of mold-free wheat at 35°C and moisture levels ranging from 15 to 31% were low and constant with time. In contrast, the mold-infected samples stored at moisture contents of 20.0% gave rapidly increasing respiration after 5 days. For that reason, the CO_2 evolved is a good index of microbial growth on grain stored under improper conditions. The respiration of grain is only

important when grain is stored for a long period of time.

MEASUREMENT OF CARBON DIOXIDE EVOLUTION

Saul and Lind (18) have reported that the carbon dioxide evolution in the drying bin was taken as measure of the combined bio-activity in the bins. They concluded that the grain was in good condition if during drying the grain had lost less than one percent of its initial dry weight.

In 1960 Saul (17) reported on the extension of the research conducted by Saul and Lind. In his study the measurement of the carbon dioxide produced by shelled corn during drying was examined. The measurements of carbon dioxide were made with a Beckman infrared gas analyser. All but one of the samples of dried corn graded U.S. No.1 or 2 when drying had been completed before a one percent loss of dry matter. Saul suggested the use of the criterion that corn should be dried with loss of not more than one percent dry matter.

In 1963 Steele (23) designed continuous aerated equipment to measure CO_2 produced by shelled corn. Six levels of temperatures (35,45,55,65,75, and 85°F), and four levels of moisture content (18,22,25, and 28%) were selected. To maintain the moisture content of the corn during the experiment, water and saturated salt solutions were used to maintain equilibrium relative humidities. From this study Steele derived an equation to predict the time that grain would lose dry matter. For example, he found that the predicted time for the grain to lose one percent dry matter at 28% moisture and 55°F was 305 hours.

In 1967 Steele (24) slightly modified the laboratory equipment to measure carbon dioxide produced by damaged shelled corn. He established a quantitative relationship between dry matter loss (0.25 - 1.0%), and the variables of temperature, moisture content and mechanical damage. He found that the time for the grain to lose 0.5% dry matter at 25% moisture, 60°F and 30% mechanical damage was 230 hours. The maximum storage life of corn was related to moisture content, temperature and mechanical damage by the following equation,

$$T = T_R \times M_T \times M_M \times M_D$$

where : T = estimated maximum storage time

T_R = time for corn having 25% moisture content and 30% mechanical damage, stored at 60°F to lose 0.5% dry matter = 230 hours

M_T = constant, from temperature multiplier chart

M_M = constant, from moisture multiplier chart

M_D = constant, from mechanical damage multiplier chart

MICROBIAL ACTIVITY

Christensen and Kaufman (2) have provided information on the role of fungi in quality loss. They divide the fungi that invade grains and seeds into two groups, primarily on the basis of their behavior : field fungi and storage fungi. In wheat, rice, barley, and oats the major field fungi that invade the kernels are species of *Alternaria*, *Cladosporium*, *Helminthosporium*, and *Fusarium*.

Cladosporium is common in cereal seeds that have been

exposed to moist weather during harvest, especially grains harvested with the hull on, such as barley, oats and rice. It may cause darkening of the invaded hulls.

Helminthosporium is common in many lots of cereal seeds especially if the weather, just before harvest, has been moist. It may cause discoloration of the seed.

Fusarium also is common in freshly harvested cereal seeds. It may result in death and discoloration of the germ of stored grain.

Storage fungi have the ability to grow in materials whose moisture content are in equilibrium with relative humidities of 70-90% at normal ambient temperatures. The two group species consistently associated with beginning deterioration are *Aspergillus restrictus* and *Aspergillus glaucus*. In grain where the moisture contents are in equilibrium with a relative humidity of less than about 78 to 80%, *Aspergillus restrictus* and *Aspergillus glaucus* are the only species that can grow. In lots with moisture contents higher than this, these two species almost invariably appear first, and may be followed by *Aspergillus candidus*, *Aspergillus ochraceus*, *Aspergillus versicolor*, *Aspergillus flavus*, and *Penicillium*.

All the storage fungi mentioned above can kill and discolor the embryo in a kernel. However, *Aspergillus candidus* and *Aspergillus flavus* are the chief cause of heating of grain. *Aspergillus ochraceus* produces a toxin, ochratoxin, and *Aspergillus flavus* produces aflatoxin.

The major conditions that influence the development of storage fungi are as follows (3) : a) the moisture content of

the stored grain, b) the temperature, c) the length of time the grain is stored, d) the degree to which the grain has already been invaded by storage fungi before it arrives at a given site, e) the amount of foreign material present in the grain as well as the amount of mechanical damage, and f) the activity of insects and mites.

RICE QUALITY

Webb and Stermer (28) reviewed the interpretation of rice quality. In the United States the quality of rice is evaluated according to grain size, shape, uniformity, appearence, milling yield, cooking and processing characteristics, cleanliness, soundness and purity.

The U.S. Grading Standard (26) set very low tolerance for heat damaged kernels. Their presence in rice is considered evidence that the rice has undergone deterioration. Heat damaged rice is considered a worse defect than some other forms of damage.

Schroeder (19) correlated heat damage with increase prevalence of storage molds but not with the temperature of the rice in the bin. He found that damaged or discolored kernels and a particular type of discoloration, an orange stain, were caused by *Penicillium puberulum*.

Schroeder and Calderwood (20) explained that rice may be downgraded for a) damaged kernels, b) heat-damaged kernels, c) change in general color, and d) musty or moldy odor. All of these factors may be caused by the activity of fungi.

Research reported to date indicates that the most active storage fungi in rice in the U.S. are species of genus *Aspergillus* (19). *Aspergillus glaucus* and *Aspergillus flavus* appear to constitute the major fungal species that invade stored rice. Many investigators discovered that species of *Aspergillus flavus* produce aflatoxin in their metabolism.

EXPERIMENTAL PROCEDURE

APPARATUS FOR MEASURING EVOLUTUION OF CO_2 FROM GRAIN SAMPLES

The apparatus used for this study was developed by Steele (24). The equipment is located at Iowa State University, Ames, Iowa. The main components of the apparatus are; a) an air compressor for the air supply, b) a refrigerator for air cooling, c) an atmospheric CO_2 absorption system, d) bottles with water at constant temperature to saturate air with water vapor, e) constant temperature boxes, to house the jars containing the grain and f) an absorption system for the CO_2 produced from the grain samples. A diagram of the system is shown in Fig.1.

Air supply for the system was provided by an air compressor and was regulated to reduce the fluctuation in pressure due to the cycling of the compressor and to control airflow. One regulator was used to maintain an incoming air pressure of 100 psig and another to control the exit pressure at 10 psig to obtain an airflow of 71 liters per minute through the entire system. Precise measurement of the airflow through each sample is not required, but some degree of control is necessary. The airflow through each sample was 45-75 milliliters per minute and screw clamp was used to adjust the airflow.

Atmospheric CO_2 present in the air entering the system was removed by scrubbing the air with potassium hydroxide in a packed column. The column was packed with one-inch saddles and the packing spryed with a solution of 360 grams of potassium hydroxide dissolved in one liter distilled water. The column was equipped with an water pump to force hydroxide solution to

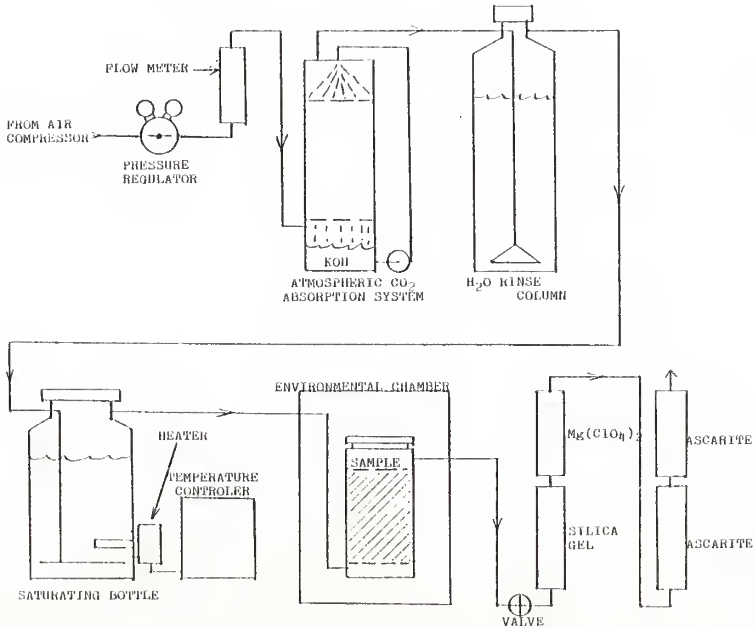


Fig. 1. FLOW DIAGRAM OF CO_2 ABSORPTION SYSTEM

spry from the top of the column. A water rinse bottle was then used to eliminate any potassium hydroxide from the air. The air was next saturated with water vapor in the saturating bottles (held at constant temperature) to establish a humidity in the air equal to the humidity above the grain at a set moisture content and temperature. Constant temperatures were maintained in the saturating bottles with mercury thermoregulators connected to an electric relay which either actuated a solenoid to permit air from the refrigerator to flow through cooling coils or to energize a submersible electric heater.

Thermoregulators were used to maintain the storage temperatures in the boxes where the sample jars were held. A fan was installed in each box to reduce temperature stratification. The grain samples were held in air-tight jars, which had a hole for incoming air at the bottom and one for outgoing air at the top. The air leaving the jar was immediately dried by passage through two drying agents in series, silica gel and magnesium perchlorate. It is necessary to remove the water from the gas stream before the stream reaches the CO_2 absorber. Silica gel was used to remove the major portion of water vapor, whereas magnesium perchlorate was used to ensure all traces of water were absorbed. After the moisture absorbing tubes, three ascarite tubes were attached in series to absorb the CO_2.

EXPERIMENTAL DESIGN

Two experiments were conducted. The design of experiment I was a 2 x 4 x 4 matrix involving 2 varieties of rice, 4 temperatures (18,24,29.5, and 35°C) and 4 moisture levels (15,18,21

and 23%) with four replicates of each condition, making a total of 128 sample jars each containing 300 g of dry weight. Experiment II was conducted at 29.5°C using 24 samples of long grain rice at 18% moisture content and 24 grain samples of medium grain at 23% moisture content. Four samples of each grain were removed when the carbon dioxide evolved was equivalent to 0.25, 0.50, 0.75, 1.0, 1.50, and 2.0% dry matter loss.

MATERIALS AND METHODS

ROUGH RICE

Two varieties of rough rice, Brazos, a medium grain, and Lebonet, a long grain, were used in this study. Both varieties were grown at Beaumont, Texas, and harvested in early September 1978. The material was transported to Manhattan, Kansas, in iced containers and was kept in cold storage at -17°C for four months. On January 5, 1979, the rice was removed from cold storage. Moisture measurement and germination tests were made on September 7,1978, and on January 5, 1979.

After four months storage, the moisture content of the medium grain, Brazos, decreased from 21% to 19% and that of long grain, Lebonet, decreased from 18% to 16%. The moisture contents of the samples were adjusted to the required levels by rewetting or drying. Rice was dried by spreading the grain on a table at room temperature. Moisture content was increased by spraying the required quantity of water on the grain in small amounts with through mixing.

When the moisture content of the grain reached a desired level, samples equivalent in weight to 300 g dry matter were placed in plastic "ziplock" bags. There were 176 plastic bags needed.

The 176 bags were transported to Ames, Iowa, on January 8, 1979 and were stored at -17°C for two weeks.

METHODS

EQUILIBRIUM RELATIVE HUMIDITY (ERH)

The moisture contents of the grain samples in the boxes were maintained at each level by passing CO_2-free air of the required relative humidity (RH) through the rice. The required relative humidity in equilibrium with the grain at each condition was calculated by use of the Chung-Pfost equation. Using psychrometric chart, the temperature required in the saturating bottles were estimated. The calculated equilibrium relative humidities (ERH) of the grain and the selected temperature of the saturating bottles are given in Appendices A-1 and A-2.

BLANK TEST

If the system was working satisfactorily, only carbon dioxide produced by the sample would be absorbed by the ascarite. A test with no grain in the jars, "blank test", was conducted for 4 levels of temperature. Five replicates for each temperature were used for 1-4 hours. The data (Table 1) resulting from this test were used to correct CO_2 produced by the grain sample.

SET-UP OF EXPERIMENT

The sample numbers are based on their position in the box. Letter "L" and "M" mean long and medium grain, respectively. For convenience, smaller numbers were used for medium grain, and larger numbers were used for long grain.

Experiment I was conducted in two runs for both varieties, long and medium grain. In the first run rice samples of 23 and 21% moisture were used. The grain samples of 18 and 15% moisture were in the second run. Experiment II was conducted along with the first run of experiment I.

MOISTURE MEASUREMENT

An electric moisture meter, Motomco (Motomco Inc, 267 Vreeland Avenue Paterson, N.Y. 07513) was used to measure the moisture content of rice samples during material preparations in Manhattan, Kansas.

An air oven method was used to measure the moisture content of grain samples in Ames at the time the experiment was set up. For each moisture level of long and medium grain rice, five of the prepared sample bags were randomly selected, and a 10 - 15 g was removed. The rough rice was dried at 130°C for 22 hours. The method was adapted from Hart et al, for oats (17). The average moisture content of those subsamples was taken as the initial moisture content of samples.

Final moisture measurement were made immediately after removing the grain from the jar. This was done on individual jars, from which a single subsample of 10-15 g of the sample was subjected to oven method. Before removing the subsamples, the grain was mixed from the top and the bottom of the jar.

The moisture content assigned to a sample of stored grain in this study was the mean of the initial and final moisture content. For example, sample 13 M in Table 2, was targeted to have a moisture content during storage of 23.0%. The initial moisture level after tempering was 22.4% whereas the final after 33 days storage at 18°C was 24.16%. The mean moisture content for the storage condition were 23.28%.

WEIGHT DETERMINATION

Initial and final weights of grain were made by using a top-loading balance. The initial weight was measured immediately before the grain was placed in the jar, and the final weight was measured immediately after the grain was removed from the jar. On a dry basis the initial dry weight and final dry weight were calculated from the initial weight and final weight, respectively. The initial dry weight was used to calculate the amount of dry matter lost in g per kg of dry matter.

DETERMINATION OF CO_2 EVOLUTION AND DRY MATTER LOSS (DML)

As carbon dioxide produced by the sample was absorbed by ascarite, the weight of ascarite tubes increased. The weight gain of the ascarite tubes for each set of four replicates was measured everyday at about the same time. A sample was removed from the storage jar when the quality of the grain appeared to the naked eye to have been lowered by invasion of destructive molds.

On the basis of simple oxidation of hexose, 10 g dry matter loss corresponds to the evolution of 14.7 g of carbon dioxide. Since 10 g dry matter loss out of 1000 g dry matter is 10g/1000g x 100% = 1%, a one percent dry matter loss corresponds to the evolution of 14.7 g carbon dioxide per kg dry matter.

RICE GRADING

After the storage experiment was completed, samples of grain from experiment I were graded officially by the USDA, Federal Grain Inspection Service in Lake Charles, Louisiana.

The four replicates of samples were combined, since the official minimum sample size is 1000 g. Only rice of 15 and 18% initial moisture content was graded, for a total of 16 samples. Rice of 21% or more initial moisture content was judged to be excessively deteriorated for grading.

Grain samples from experiment II with DML of 1% or less were individually milled and graded unofficially, since individual sample weight were only 300 g. Unofficial grading was conducted in Kansas State University based on U.S. Grading Standard for rough rice.

RESULTS AND DISCUSSION

BLANK TEST

The data collected from "blank test" is given in Table 1 (p. 21). The results show that the error ranged from 0.0006 - 0.0013 g per hour. The average error was 0.000995 g, and a correction of 0.001 g per hour for each sample was made before the CO_2 evolution in gram per initial dry weight was converted to CO_2 evolution in gram per kg dry weight. For example, in Appendix B-1, uncorrected CO_2 produced by 301 g dry weight of medium grain (sample No.13 M) at 95°F (35°C), 21.0% moisture and 18 hours was 0.868 g. Corrected CO_2 evolution was 0.868g - 18(0.001 g) = 0.85 g per 301 g dry matter. Converted CO_2 evolution was 0.85g/301g dry matter x 1000g/1kg = 2.83 g/kg dry matter. Since 1% DML was equivalent to 14.7 g CO_2/kg dry matter, dry matter loss was calculated as 2.83/14.7 x 1%DML = 0.192% DML. If the correction is not made, dry matter loss would be 0.868 x 1000/301/14.7 x 1% DML = 0.196% DML. The difference is not significant even if the correction is ignored.

EXPERIMENT I

The experimentally observed data on initial and final weights (w.b.) and initial and final moisture contents for long and medium grain rice at 18, 24, 29.5, and 35°C are shown in Tables 2 - 5. The average moisture content was the mean of the initial and final moisture content. The initial and final dry weights were calculated from initial and final weights.

Table 1. Weight increase of ascarite tubes in the "Blank Test" with no grain in sample jars.

Box temperature °C	Jar No.	Duration time h	Total weight increase g	Weight increase g/h
35	13	2	0.0024	0.0012
35	19	3	0.0033	0.0011
35	28	1	0.0008	0.0008
35	33	4	0.0040	0.0010
35	35	2	0.0018	0.0009
29.5	13	3	0.0036	0.0012
29.5	18	2	0.0014	0.0007
29.5	20	2	0.0020	0.0010
29.5	31	3	0.0018	0.0006
29.5	36	1	0.0011	0.0011
24	19	4	0.0028	0.0007
24	22	1	0.0013	0.0013
24	25	3	0.0027	0.0009
24	30	3	0.0024	0.0008
24	32	1	0.0012	0.0012
18	16	1	0.0011	0.0011
18	17	3	0.0030	0.0010
18	24	4	0.0032	0.0008
18	25	2	0.0026	0.0013
18	29	4	0.0048	0.0012
			Total	0.0199
			Average	0.000995

Table 2. Initial and final weight and moisture content for medium and long grain at 18°C.

Sample No.	Storage Time days	Weight (w.b) I	Weight (w.b) F	Moisture[a] I	Moisture[a] A	Moisture[a] F	Weight (d.b) I	Weight (d.b) F
Medium grain								
13 M	33	373.20	375.21	22.40	23.28	24.16	289.60	284.56
16 M	33	388.70	384.73	22.40	22.75	23.10	301.63	295.86
19 M	33	388.45	383.85	22.40	22.71	23.02	301.44	295.49
22 M	33	389.10	389.88	22.40	23.14	23.88	301.94	296.78
14 M	43	378.60	376.50	20.70	21.13	21.56	300.23	295.33
17 M	43	363.80	363.71	20.70	21.18	21.66	288.49	284.93
20 M	43	378.50	377.92	20.70	21.25	21.80	300.15	295.54
23 M	43	363.20	365.20	20.70	21.34	21.98	288.02	284.95
13 M	83	364.90	363.74	18.33	18.85	19.36	298.01	293.32
16 M	83	365.90	365.49	18.33	19.00	19.67	298.54	293.60
19 M	83	346.45	343.55	18.33	18.61	18.88	282.95	278.69
22 M	83	364.80	362.73	18.33	18.68	19.02	297.93	293.74
15 M	80	353.25	353.16	15.27	15.69	16.11	299.31	296.27
18 M	80	354.10	355.80	15.27	15.83	16.39	300.03	297.49
21 M	80	335.20	335.94	15.27	15.76	16.24	284.01	281.39
24 M	80	353.50	355.33	15.27	15.93	16.59	299.52	296.38
Long grain								
25 L	18	386.15	287.39	22.25	23.01	23.77	300.23	295.31
28 L	18	366.70	370.50	22.25	23.24	24.23	285.11	280.73
31 L	18	368.00	368.94	22.25	22.99	23.73	286.12	281.39
34 L	18	386.70	385.46	22.25	22.90	23.54	300.66	294.73
26 L	37	362.45	362.69	20.50	21.14	21.78	288.15	283.70
29 L	37	379.25	376.20	20.50	20.95	21.40	301.50	295.70
32 L	37	361.70	367.60	20.50	20.78	21.06	287.55	282.83
35 L	37	363.60	367.45	20.50	21.31	22.11	289.06	283.63
25 L	83	364.10	367.15	17.90	18.72	19.54	298.93	295.41
28 L	83	365.00	367.38	17.90	18.79	19.68	299.67	295.08
31 L	83	364.30	364.53	17.90	18.52	19.13	299.09	294.80
34 L	83	348.79	363.03	17.90	18.67	19.44	286.36	292.46
27 L	79	352.10	354.39	15.15	15.79	16.42	298.76	296.20
30 L	79	352.10	356.89	15.15	16.12	17.09	298.76	295.90
33 L	79	338.65	340.20	15.15	15.81	16.46	287.34	284.20
36 L	79	352.30	354.60	15.15	15.95	16.74	298.93	295.27

a) I = Initial F = Final A = Average

Table 3. Initial and final weight and moisture content for medium and long grain at 24°C.

Sample No.	Storage Time days	Weight (w.b) I	Weight (w.b) F	Moisture[a] I	Moisture[a] A	Moisture[a] F	Weight (d.b) I	Weight (d.b) F
Medium grain								
13 M	24	389.50	384.92	22.40	22.63	22.86	302.25	296.93
16 M	24	388.65	383.14	22.40	22.50	22.60	301.59	296.55
19 M	24	389.15	380.65	22.40	22.20	21.99	301.98	296.95
22 M	24	376.98	368.97	22.40	22.15	21.89	292.54	288.20
14 M	37	379.80	375.42	20.70	20.79	20.87	301.18	297.07
17 M	37	365.70	353.74	20.70	19.93	19.15	289.99	286.06
20 M	37	379.20	375.73	20.70	20.75	20.80	300.71	297.58
23 M	37	379.10	370.14	20.70	20.29	19.88	300.63	296.56
13 M	45	365.20	366.58	18.33	18.80	19.27	298.26	295.94
16 M	45	351.87	350.76	18.33	18.44	18.55	287.37	285.69
19 M	45	365.25	363.89	18.33	18.57	18.81	298.30	295.44
22 M	45	365.05	360.05	18.33	18.13	17.92	298.14	295.53
15 M	80	337.15	339.00	15.27	15.77	16.27	285.67	283.90
18 M	80	352.95	353.55	15.27	15.51	15.74	299.05	297.90
21 M	80	355.75	342.36	15.27	15.54	15.81	290.20	288.23
24 M	80	342.50	342.66	15.27	15.60	15.92	290.20	288.11
Long grain								
25 L	18	386.90	375.90	22.25	21.74	21.23	300.81	296.09
28 L	18	387.20	382.04	22.25	22.59	22.92	301.05	294.48
31 L	18	369.89	360.84	22.25	22.16	22.06	287.59	281.24
34 L	18	387.30	376.90	22.25	22.05	21.85	301.13	294.56
26 L	30	379.60	370.60	20.50	20.39	20.28	301.78	295.44
29 L	30	379.45	372.30	20.50	20.32	20.13	301.66	297.36
32 L	30	379.20	371.63	20.50	20.31	20.11	301.46	296.91
35 L	30	379.35	374.25	20.50	20.60	20.69	301.58	296.82
25 L	45	348.12	348.47	17.90	18.43	18.96	285.81	282.40
28 L	45	350.35	347.22	17.90	18.00	18.10	287.64	284.37
31 L	45	365.30	365.28	17.90	18.33	18.75	299.91	296.79
34 L	45	364.15	366.19	17.90	18.63	19.36	299.97	295.30
27 L	63	352.60	352.61	15.15	15.45	15.74	299.18	297.11
30 L	63	352.20	353.12	15.15	15.51	15.87	298.84	297.08
33 L	63	352.52	353.08	15.15	15.43	15.70	299.10	297.65
36 L	63	338.60	340.05	15.15	15.49	15.82	287.30	286.25

a) I = Initial F = Final A = Average

Table 4. Initial and final weight and moisture content for medium and long grain at 29.5°C.

Sample No.	Storage Time days	Weight (w.b) I	Weight (w.b) F	Moisture a) I	Moisture a) A	Moisture a) F	Weight (d.b) I	Weight (d.b) F
Medium grain								
13 M	18	376.17	361.90	22.40	21.55	20.69	291.91	287.02
16 M	18	389.10	374.12	22.40	21.59	20.78	301.94	296.38
19 M	18	387.40	374.13	22.40	21.75	21.10	300.62	295.19
22 M	18	388.80	378.15	22.40	22.08	21.76	301.71	295.87
14 M	23	378.60	365.58	20.70	19.76	18.82	300.23	296.78
17 M	23	365.41	350.57	20.70	19.57	18.43	289.77	285.96
20 M	23	379.20	378.53	20.70	21.24	21.77	300.71	296.13
23 M	23	379.60	367.35	20.70	19.93	19.15	301.02	297.00
15 M	41	354.75	345.40	18.33	17.63	16.93	289.72	286.94
18 M	41	365.85	358.40	18.33	17.74	17.15	298.79	296.94
21 M	41	365.90	358.35	18.33	17.77	17.21	298.83	296.68
24 M	41	365.72	358.32	18.33	17.81	17.28	298.68	296.40
15 M	43	335.35	331.79	15.27	15.01	14.74	284.14	282.88
18 M	43	354.25	349.40	15.27	14.91	14.55	300.16	298.56
21 M	43	352.20	348.43	15.27	15.00	14.73	298.42	297.11
24 M	43	352.10	347.38	15.27	14.93	14.59	298.33	296.70
Long grain								
25 L	8	371.85	363.25	22.25	21.97	21.69	289.11	284.46
28 L	8	387.10	376.31	22.25	21.60	20.95	300.97	297.47
31 L	8	386.80	374.91	22.25	21.53	20.81	300.74	296.90
34 L	8	386.85	375.50	22.25	21.72	21.18	300.78	295.97
26 L	18	379.40	372.52	20.50	20.16	19.81	301.62	298.72
29 L	18	379.28	369.36	20.50	20.07	19.64	301.62	296.82
32 L	18	379.60	368.55	20.50	19.99	19.47	301.78	296.79
35 L	18	362.77	354.37	20.50	20.18	19.86	288.40	283.99
27 L	41	365.40	355.26	17.90	17.24	16.57	299.99	296.39
30 L	41	365.45	357.42	17.90	17.46	17.02	300.03	296.59
33 L	41	353.40	344.58	17.90	17.28	16.65	290.14	287.21
36 L	41	365.42	357.55	17.90	17.50	17.10	300.01	296.41
27 L	43	352.15	348.69	15.15	14.96	14.77	298.80	297.19
30 L	43	339.00	332.75	15.15	14.90	14.64	287.64	284.04
33 L	43	339.30	337.40	15.15	15.09	15.02	287.90	286.72
36 L	43	352.40	351.23	15.15	15.12	15.08	299.01	298.26

a) I = Initial F = Final A = Average

Table 5. Initial and final weight and moisture content for medium and long grain at 35°C.

Sample No.	Storage Time days	Weight (w.b) I	Weight (w.b) F	Moisture a) I	Moisture a) A	Moisture a) F	Weight (d.b) I	Weight (d.b) F
Medium grain								
13 M	18	388.35	367.76	22.40	21.05	19.69	301.36	295.35
16 M	18	374.21	356.00	22.40	21.06	19.72	290.39	285.80
19 M	18	373.44	353.65	22.40	21.02	19.63	289.79	284.23
22 M	18	388.85	370.23	22.40	21.16	19.92	301.75	296.48
14 M	35	379.15	367.57	20.70	20.15	19.59	300.67	295.56
17 M	35	365.36	348.57	20.70	19.70	18.70	289.73	283.39
20 M	35	379.20	362.20	20.70	19.78	18.86	300.71	293.89
23 M	35	378.60	362.49	20.70	19.70	18.70	300.23	294.71
13 M	41	350.50	339.72	18.33	17.60	16.87	286.25	282.41
16 M	41	367.35	357.73	18.33	17.76	17.19	300.01	296.24
19 M	41	351.91	343.04	18.33	17.78	17.22	287.40	283.97
22 M	41	366.50	352.79	18.33	17.34	16.35	299.32	295.11
15 M	41	352.50	348.35	15.27	14.94	14.60	298.67	297.49
18 M	41	338.83	333.11	15.27	14.73	14.18	287.09	285.88
21 M	41	353.40	343.35	15.27	14.25	13.23	299.44	297.93
24 M	41	353.50	347.36	15.27	14.77	14.27	299.52	297.79
Long grain								
25 L	8	387.40	373.45	22.25	21.47	20.68	301.20	296.22
28 L	8	386.00	374.90	22.25	21.78	21.30	300.12	295.05
31 L	8	387.85	372.80	22.25	21.29	20.33	301.55	297.00
34 L	8	371.88	360.10	22.25	21.36	20.25	289.14	286.39
26 L	18	365.66	355.32	20.50	19.99	19.47	290.70	286.14
29 L	18	379.80	365.15	20.50	19.72	18.93	301.94	296.03
32 L	18	379.50	369.59	20.50	20.02	19.54	301.70	297.37
35 L	18	379.45	365.20	20.50	19.56	18.62	301.66	297.20
25 L	42	350.83	340.75	17.90	17.55	17.19	288.03	282.18
28 L	42	365.00	353.80	17.90	17.29	16.67	299.67	294.82
31 L	42	364.50	355.78	17.90	17.51	17.12	299.25	294.87
34 L	42	364.15	342.92	17.90	17.41	16.92	298.97	297.38
27 L	41	352.50	342.30	15.15	14.22	13.28	299.10	297.16
30 L	41	333.10	329.56	15.15	14.89	14.62	282.63	281.97
33 L	41	353.00	346.56	15.15	14.59	14.02	299.52	297.97
36 L	41	352.80	342.97	15.15	14.18	13.20	299.35	297.70

a) I = Initial F = Final A = Average

The storage times for each condition are shown also.

The data in Tables 2 - 5 (pp. 22- 25) shows a problem was encountered in this study to maintain the initial moisture content of the rice. Although no test was conducted on temperature and relative humidity of the incoming air for the box, the final moisture contents of the grain indicated some shift in the humidity of the incoming air. In the box at 35°C, all moisture contents decreased 0.5-2.0%. On the other hand, in the box at 18°C all moisture contents increased 1-2%. Some samples increased in moisture content whereas others decreased in the boxes of 24 and 29.5°C. It is believed that temperature played a leading role in that situation. The deficiency of insulation on the equipment and the difference between the temperatures of the room, the saturating bottles and inside the boxes probably caused of the problem. Two situations are considered in Fig.2a (p. 27). The first condition is when $T_1 < T_3$, where T_1 is temperature of saturating bottle, 60°F (15.5°C), T_2 is temperature of air passing through the grain in the box, 65°F (18°C), and T_3 is room temperature, 21-26°C (69-79°F). Under ideal conditions, air saturated at 60°F (15.5°C) in the saturating bottle maintains 85% relative humidity in a constant temperature box of 65°F (18°C). However, if the temperature of the saturating bottle and the connecting line are higher than 60°F (15.5°C), the air in the bottle would gain more moisture vapor and have a higher relative humidity than 85% at 65°F (18°C). The higher equilibrium relative humidity did not maintain the calculated ERH, and the moisture content of the samples increased.

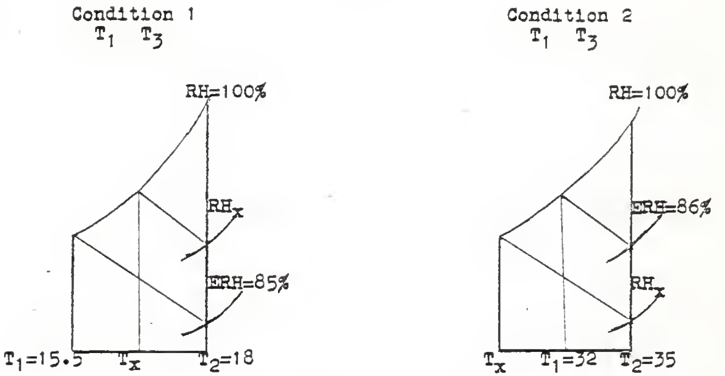


Fig.2a. The effect of temperatures on the conditions in the system are illustrated by the use of psychrometric chart

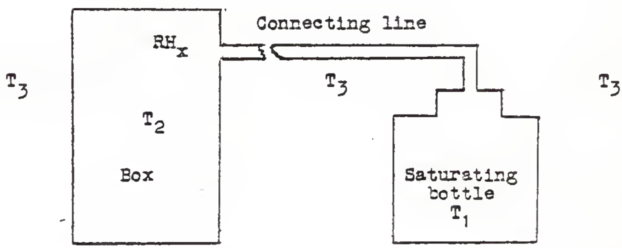


Fig.2b.Schematic diagram of the system

T_1 = temp. of saturating bottle

T_2 = temp. of air in the box

T_3 = room temp., 69-79°F (21-26°C)

T_x = undetected temp.

RH_x = undetected relative humidity

The second situation is where $T_1 > T_3$, and $T_1 = 90^{\circ}F$ ($32.2^{\circ}C$), $T_2 = 95^{\circ}F$ ($35^{\circ}C$), and $T_3 = 69\text{-}79^{\circ}F$ ($21\text{-}26^{\circ}C$). When temperature T_1 was lower than $90^{\circ}F$ ($32.2^{\circ}C$), the air passing through the bottle gained less water vapor than needed. Thus, the air at $95^{\circ}F$ had a lower relative humidity lower than 86%. The lower relative humidity caused the moisture content of the grain at $95^{\circ}F$ ($35^{\circ}C$) to decrease.

Carbon dioxide produced by medium and long grain rice samples stored at 4 temperatures and 4 moisture contents are shown in 32 tables collected in Appendix B. A portion of Appendix B, shown below is an example of the data collected for four replicate samples at $95^{\circ}F$ ($35^{\circ}C$) and 21.48% average moisture content.

Table B-17. Carbon dioxide (g/kg of dry matter) produced by long grain rice at $35^{\circ}C$ and 21.48% moisture content.

Time h.	Replicate Samples				
	No.25L	No.28L	No.31L	No.34L	Mean CO2
25	4.24	2.34	2.65	3.89	3.28
51	8.08	6.27	6.54	7.75	7.16
71	10.93	9.05	9.37	10.57	9.98

The storage moisture listed for the samples was the mean of the initial and final moisture level of the stored samples as shown in Tables 2 - 5. The last columns of Tables B-1 to B-32 is the mean value of CO_2 evolution of the four replicate samples at the indicated time. The unit of CO_2 evolution is

grams per kilogram dry matter.

The U.S. Official grade of samples stored at four temperatures (18, 24, 29.5, and 35°C) and two moisture levels (15 and 18%) is shown in Table 6 (p.30). The grade of the samples ranged from U.S. No.1 to U.S. Sample Grade. The samples stored at the two higher moisture levels (21 and 23%) were not graded because the rice was badly deteriorated.

Using the data in Table 6, the relationship between DML and Grading Standards of the 11 officially graded samples held for 42 days can be summarized as follows

Grade No.	% DML
1	0.43, 0.47, 0.52, 0.53
2	0.76, 0.77
3	0.98, 1.05
4	1.14, 1.26
5	1.37

Regardless of the effect of temperature, moisture content, and variety, the samples held for 42 days were graded U.S. No.1, 2, 3, 4 and 5 when the rice had lost approximately 0.5, 0.75, 1.0,1.20 and 1.40% dry matter, respectively. The data shown the % DML is a good index of quality of rough rice. The samples were of good market quality (U.S. No.1 and No.2) when the samples had lost less than 0.75% dry matter.

The effect of storage time on the grade of the samples held at approximately 15% initial moisture content with various storage time is as follows

Table 6. Dry matter loss (DML) and U.S. Official Grades of rough rice stored at 15% and 18% moisture content and four temperatures (18,24,29,35°C).

Test condition								
Temp. °C	Initial m.c.	Time days	Sample No.	DML %	Grade No.	Damaged kernels %	Milling whole %	Yield total %
			Medium grain					
18	18.33	83	13,16,19,22-M	1.42	S[a]	13.1	46	51
18	15.27	80	15,18,21,24-M	1.01	4	3.1	59	69
24	18.33	45	13,16,19,22-M	0.77	2	1.5	61	71
24	15.27	80	15,18,21,24-M	0.66	4	3.6	56	69
29.5	18.33	41	15,18,21,24-M	0.76	2	1.4	62	70
29.5	15.27	43	15,18,21,24-M	0.43	1	0.5	60	71
35	18.33	41	13,16,19,22-M	1.14	4	3.2	58	70
35	15.27	41	15,18,21,24-M	0.47	1	0.4	60	71
			Long grain					
18	17.90	83	25,28,31,34-L	1.41	S[a]	12.0	41	60
18	15.15	79	27,30,33,36-L	0.98	3	1.8	48	55
24	17.90	45	25,28,31,34-L	1.26	4	2.3	54	69
24	15.15	63	27,30,33,36-L	0.60	3	1.5	54	68
29.5	17.90	41	27,30,33,36-L	1.05	3	2.0	56	69
29.5	15.15	43	27,30,33,36-L	0.53	1	0.3	57	70
35	17.90	42	25,28,31,34-L	1.37	5	5.0	58	69
35	15.15	41	27,30,33,36-L	0.52	1	0.5	54	69

a) U.S. Sample Grade.

Grade No.	% DML	Storage time, days
1	0.43, 0.47, 0.52, 0.53	42
3	0.60	63
4	0.66	80

The increase of storage time did not cause much increase in terms of % DML, but it did lower quality. The data in Table 6 in general, shows that an increase of storage time caused an increase in percentage of damaged kernels which lowered the grade of rough rice.

The effect of storage temperature shown in Table 6 (p.30) on two pairs of samples at 15% initial moisture content and 40 days storage time is summarized as below

Grade No.	% DML	Storage temperature	Variety
1	0.53	85°F (29.5°C)	Long
1	0.52	95°F (35°C)	Long
1	0.43	85°F (29.5°C)	Medium
1	0.47	95°F (35°C)	Medium

It appears there is no significant effect of storage temperature. However, an interaction between temperature and moisture content for a pair of medium grain samples stored in 80 days is shown below (data from Tables 2 and 6)

Grade No.	% DML	Storage temperature	Moisture initial %	Moisture final %
4	1.06	65°F (18°C)	15.27	16.33
4	0.66	75°F (24°C)	15.27	15.92

In this case, it appears the effect of final moisture increase % DML.

In another case medium grain and long grain stored at 18% initial moisture and $18^{\circ}C$ for 80 days had 1.40% DML (Table 6). The final moisture content of the medium grain was 1% higher than the initial and final moisture content of long grain was 1.5% higher. Many damaged kernels were produced and the rice was graded U.S. Sample Grade.

The data on milling yield can be summarized as below

Grade No.	Milling yield % Whole kernels	% Total
1	54,57,60,60	69,70,71,71
2	61,62	70,71
3	48,54,56	55,68,69
4	54,58,56,59	69,69,69,70
5	58	69
U.S.Sample	41,46	51,60

There was no clear relationship between the grade and milling yield. The % total of milling yield of the samples graded No. 1-5 are about the same, except one sample graded No. 3 had % total milling yield of 55%. The milling yield for the grain graded U.S. Sample Grade is significantly lower than that of others yield.

EXPERIMENT II

In experiment II, long grain rice at 18% moisture content and medium grain rice at 22% moisture content were held at $29.5^{\circ}C$. Four samples of each variety were removed when CO_2 evolution to fixed amounts of dry matter loss. The relationships of DML to grade are shown in Tables 7 and 8 (pp.33and 34).

Table 7. Carbon dioxide evolved, time required, grade and milling yield for long grain rice held at 29.5°C and 18% moisture until a fixed amount (0.25,0.50, 0.75,1.0,1.50,2.0%) of dry matter was lost.

Sample No.	Final M.C. %	Time h.	CO_2 g/kg	DML %	Grade No.	Damaged kernels %	Milling Yield whole %	Milling Yield total %
2 L	18.11	138.6	3.57	0.24	1	0.2	53.09	70.99
6 L	17.73	184.1	3.91	0.26	1	0.3	58.64	72.22
12 L	17.96	184.2	4.00	0.27	1	0.2	55.55	70.99
45 L	17.04	138.8	3.59	0.24	1	0.3	53.09	70.37
5 L	17.12	311.4	7.45	0.50	2	1.2	54.32	70.99
9 L	18.64	292.9	6.08	0.41	1	0.5	53.76	70.42
21 L	18.03	320.8	7.40	0.50	1	0.3	52.46	70.37
27 L	17.49	348.8	7.64	0.52	2	1.5	53.70	70.99
3 L	18.32	551.9	10.35	0.70	3	2.5	51.42	69.37
8 L	17.27	538.6	10.66	0.73	3	2.2	47.53	69.81
17 L	17.69	592.6	11.03	0.75	3	2.4	54.32	69.14
24 L	18.22	592.9	10.35	0.79	3	2.3	52.47	69.75
11 L	17.46	740.1	14.44	0.98	4	3.5	47.76	70.20
23 L	17.21	717.5	15.12	1.03	4	3.6	45.06	68.52
39 L	16.97	652.1	14.46	0.98	4	3.2	53.70	70.37
48 L	17.84	638.7	14.34	0.98	4	3.3	51.98	66.66
14 L	16.56	1240.2	23.60	1.61	NOT	GRADED	b)	
15 L	17.03	1239.1	22.50	1.53	,,	,,		
18 L	16.84	1240.0	21.60	1.47	,,	,,		
36 L	16.78	1239.0	22.12	1.50	,,	,,		
20 L	17.11	1491.0	30.59	2.08	,,	,,		
30 L	17.24	1491.1	28.28	1.92	,,	,,		
33 L	16.60	1440.6	28.47	1.94	,,	,,		
42 L	16.17	1492.9	27.96	1.90	,,	,,		

b) Samples were not graded and estimated as U.S. Sample Grade.

Table 8. Carbon dioxide evolved, time required, grade and milling yield for medium grain rice held at 29.5°C and 22% moisture until a fixed amount (0.25,0.50, 0.75,1.0,1.50,2.0%) of dry matter was lost.

Sample No.	Final M.C. %	Time h,	CO_2 g/kg	DML %	Grade No.	Damaged kernels %	Milling Yield whole %	Milling Yield total %
22 M	21.56	65.8	3.68	0.25	2	1.4	51.23	71.60
28 M	22.01	61.7	3.29	0.22	2	1.5	45.06	72.84
32 M	21.73	61.9	3.70	0.25	2	1.5	50.62	70.37
35 M	20.96	66.8	3.99	0.29	2	1.1	49.38	69.14
1 M	22.23	90.7	7.64	0.52	5	4.4	45.06	69.75
13 M	21.84	98.0	7.35	0.50	5	4.5	50.62	70.99
16 M	22.60	96.9	8.06	0.55	4	3.6	48.15	69.14
43 M	22.08	97.9	7.27	0.50	4	3.4	51.23	70.37
34 M	21.77	137.7	11.58	0.79	S[a]	12.0	49.51	63.58
41 M	20.85	145.0	10.82	0.70	S	13.7	46.30	64.81
44 M	22.21	144.8	10.50	0.70	S	13.5	48.27	64.20
46 M	21.79	137.8	11.93	0.81	S	14.3	41.97	66.05
7 M	20.29	231.3	15.00	1.02		-	-	-
29 M	21.07	232.7	14.65	1.00	S	21.3	43.21	66.66
31 M	22.05	231.3	14.31	0.97	S	18.2	39.60	62.34
38 M	20.17	245.6	14.66	1.00	S	16.3	43.21	68.52
40 M	21.68	245.3	14.68	1.00	S	21.4	46.91	67.90
10 M	21.70	338.6	25.46	1.73	NOT	GRADED[b]		
26 M	20.45	322.8	24.63	1.68	,,	,,		
47 M	21.19	318.9	22.32	1.52	,,	,,		
4 M	20.43	431.2	39.36	2.68	,,	,,		
19 M	20.68	417.5	29.15	1.98	,,	,,		
25 M	21.27	431.4	31.67	2.15	,,	,,		
37 M	20.40	432.6	28.83	1.96	,,	,,		

a) S = U.S. Sample Grade.

b) Samples were not graded and estimated as U.S. Sample Grade.

Dry matter loss (DML) was converted from CO_2 evolution data. The samples that lost dry matter more than 1.0% were assigned U.S. Sample Grade, because of their appearance. They were not milled or graded.

Samples of long grain rice with 0.25% DML were graded U.S. No. 1 (Table 7). The samples with 0.5% DML were graded No. 1 or No. 2. Rice with these grade are of good market quality. The sample with 0.75% and 1.0% dry matter loss were graded No. 3 and No. 4, respectively. Comparing the results from experiment I for long grain held at 29.5°C and 18% moisture (Table 6) the sample of grain with 1.05% DML was graded No.3, but four replicates were graded No.4 in experiment II. Since there was the same treatment for the grain in both experiments, the difference was caused by random error. The data on milling yield shows no clear relation to grade as was also the case in experiment I. However, milling yield will not increase as the grain quality is lowered.

The results from experiment II on medium grain rice are shown in Table 8. The data shows different results on grading from those of long grain held at 18% moisture content at the same temperature. The samples with 0.25% dry matter loss were graded No.2 and the time for the grain to lose 0.25% dry matter was 65 hours. The samples with 0.50% dry matter loss were graded No.4 and 5. The samples of 0.70% and 1.0% dry matter loss were graded U.S. Sample Grade.

DATA ANALYSIS

The effect of temperature and moisture content on CO_2 evolved with time was obtained in experiment I on long and medium grain rice. Such experimental data can be used to establish the relationship between dry matter loss and temperature, moisture content and time.

A model equation for predicting DML has been developed by Vemuganti from shelled corn data obtained from Steele (24); it is designated the KSU-DML-MODEL. The data from experiment I was used in this study to test the validity of the model for the temperature, moisture content and time relationships to DML in rough rice.

The model equation is :

$$DML = 1 - EXP\left[-(A \times t^{C}) \times EXP\{D \times (T-60)\} \times EXP\{E \times (W-0.14)\}\right]$$

where :

A, C, D and E are constants to be determined in this analysis

DML = dry matter loss in decimal form

t = time of storage in hours/1000

T = temperature, ^{o}F

W = moisture content wet basis (decimal)

A non-linear least-square regression program called GAUSHAUS from the SHARE Library was used to find constants in the model. The constants found are shown in Appendix C-1 to C-3, for long grain, medium grain and pooled long and medium grsin, respectively. A statistical analysis of the dry matter loss

model and discussion are given in Appendix D.

When the equation was fitted to experimental data, curves were produced showing the relationship of DML to time (40 days maximum) for long and medium grain rough rice at four temperature and four moisture levels (Fig. 3-10, pp.38 - 45). The equation or curves can be used to predict the time when rough rice at the given conditions has reached an amount of % DML. For example, in the curve shown in Fig. 8 (p. 43) the time for medium grain rice at 22% moisture and 29.5°C to lose 0.25% dry matter is 25 hours. Medium grain rice stored at the above condition were graded U.S. No.2 in experiment II (Table 8,p.34). Therefore, the maximum holding time for medium grain rice to remain in good condition at 22% moisture content and 29.5°C is 25 hours. In yet another example, the time for long grain rice at 18% moisture and 29.5°C to lose 0.50% dry matter is 320 hours (see Fig. 7,p. 42). At that time the grain samples at this condition were graded U.S. No. 1 and 2. The maximum holding time for long grain rice at 18% moisture content and 29.5°C is 320 hours.

Those results can be summarized as follow

Variety	Grade No.	DML %	Moisture content %	Maximum holding time, h.
Medium	2	0.25	22	25
Long	1 - 2	0.50	18	320

The effect of moisture content on the amount of dry matter loss and the maximum storage time is clearly shown. Rough rice at a lower moisture content remains in a good condition for a

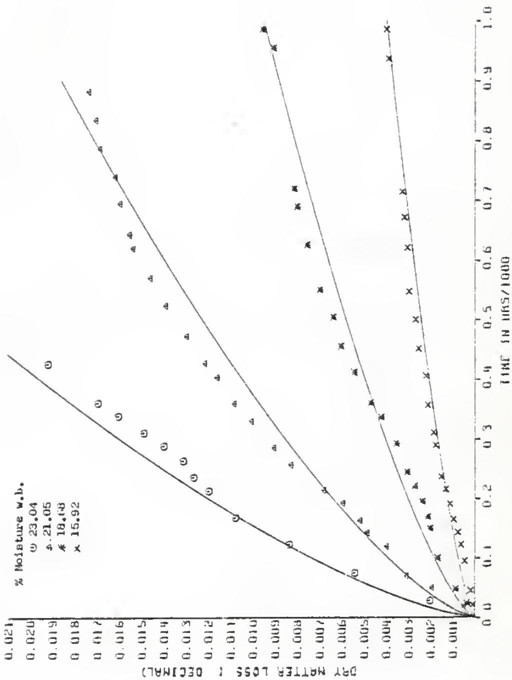


FIG. 3 DRY MATTER LOSS VS TIME AT 65 DEG.F LONG GRAIN

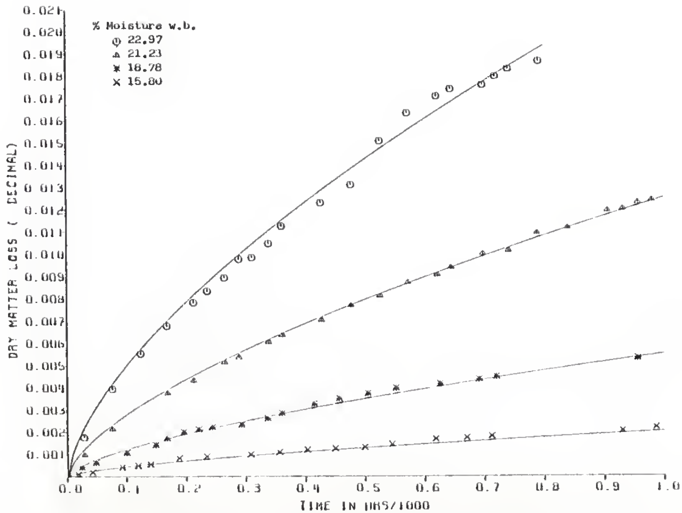


FIG. 4 DRY MATTER LOSS VS TIME AT 65 DEG.F MED. GRAIN

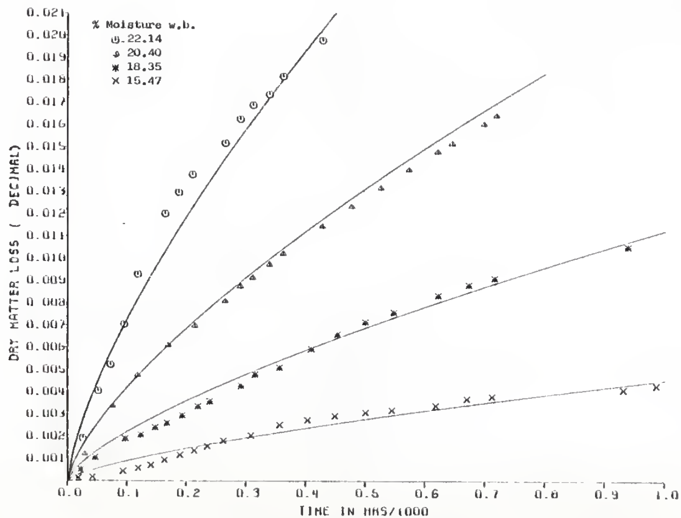


FIG. 5 DRY MATTER LOSS VS TIME AT 75 DEG.F LONG GRAIN

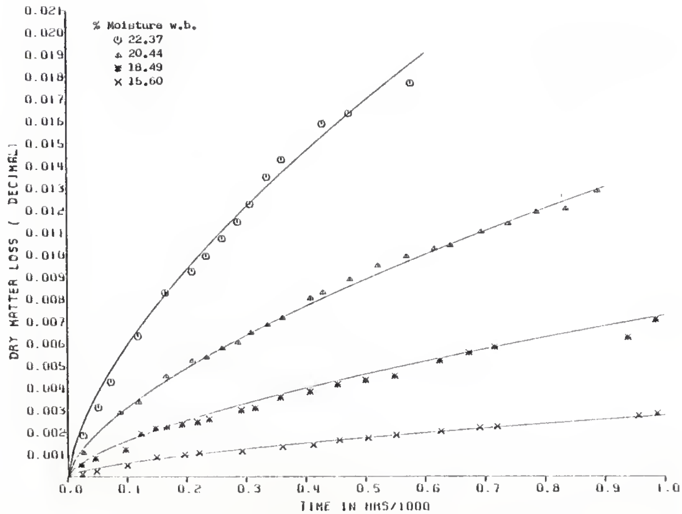


FIG. 6 DRY MATTER LOSS VS TIME AT 75 DEG.F MED. GRAIN

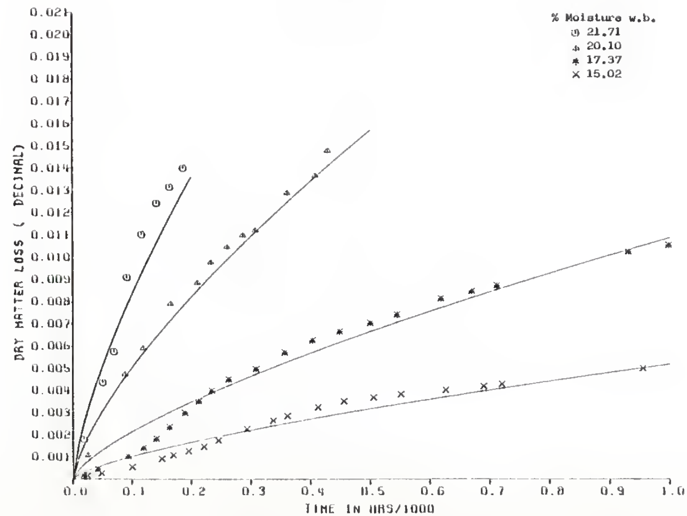


FIG. 7 DRY MATTER LOSS VS TIME AT 85 DEG.F LONG GRAIN

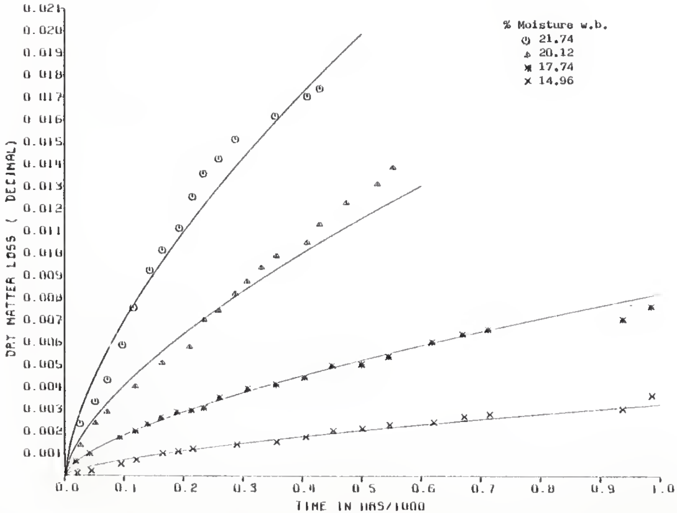


FIG. 8 DRY MATTER LOSS VS TIME AT 85 DEG.F MED. GRAIN

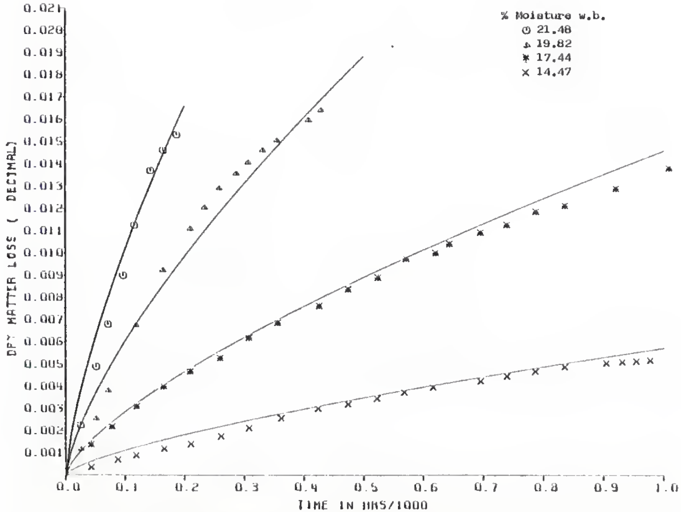


FIG. 9 DRY MATTER LOSS VS TIME AT 95 DEG.F LONG GRAIN

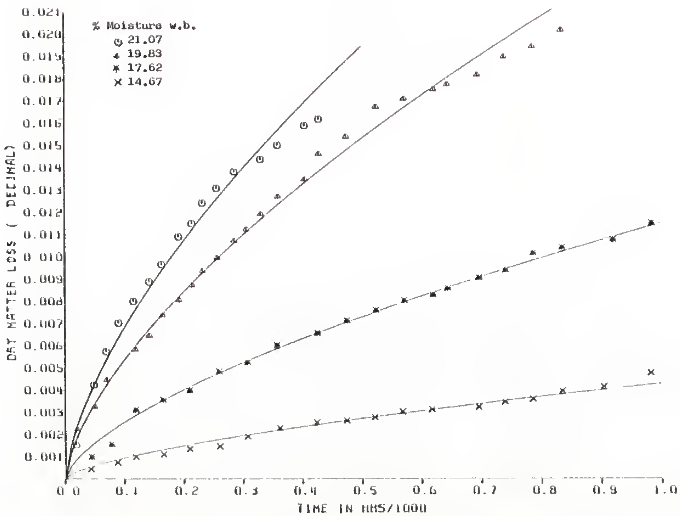


FIG. 10 DRY MATTER LOSS VS TIME AT 95 DEG.F MED. GRAIN

longer time even though it shows a greater % DML than rough rice at a high moisture content.

Those results suggest that rough rice at 14% moisture content might remain sound even if the rice lost 1% dry matter. Experiment should be done in the future to answer at speculation. The hypothesis that rough rice at 14% moisture content will remain sound at 1% DML is based on the following reasoning. The downgrading of rough rice is due mostly to the number of damaged kernels present in a sample. The number of damaged kernels decreases sharply as the moisture content of the grain decreases. At 14% moisture content very few kernels would be expected to be damaged even though a 1% DML might be observed. Rough rice at 14% moisture content is a poor substrate for mold growth, because the ERH is 70-75%. In that condition only *Aspergillus restrictus* and *Aspergillus glaucus* grow and cause lowering of grain quality. If it is assumed that rough rice stored at 14% moisture content and 35°C would be in good condition when DML is 1%, the equation predicts the safe storage time for long grain rough rice to be 113 days, and for medium grain 216 days. That there was a difference between the samples of long and medium grain rice used in this study was determined statistically in Appendix E. The conclusion is that the long grain rice used in this study behaved significantly different from the medium grain.

SUMMARY AND CONCLUSIONS

1. The deterioration of rough rice was measured by the evolution of carbon dioxide.
2. Dry matter loss depended on moisture content, temperature and storage period. Dry matter loss can be predicted by the model equation KSU-DML-MODEL. Data from two different varieties of rough rice (long and medium grain) were used to find constants in the model.
3. The permissable percentage of dry matter loss of rough rice, at which the rice remained in good condition, was found to depend on moisture level. The medium grain rice at 22% moisture and 85°F (29.5°C) graded U.S. No.2 when it had lost 0.25% dry matter. The long grain rice at 18% moisture and 29.5°C graded U.S. No. 1 or No. 2 when it had lost 0.50% dry matter. On the other hand, the medium grain rice at 22% moisture and 85°F graded U.S. No. 5 at a DML of 0.50%.
4. The medium grain rice at 22% moisture content and 29.5°C could be stored only 2 days before the grain was downgraded. The long grain rice at 18% moisture content and 29.5°C could be stored 14 days before deterioration reduced the grade of the grain. Therefore, a maximum holding time for medium grain rice at 22% moisture and 29.5°C is 2 days. Long grain at 18% moisture and 29.5°C can be held 14 days.
5. The maximum storage time for rough rice at 14% moisture can be estimated by the use of KSU-DML-MODEL. If the grain at 14% moisture and 35°C is assumed to be good condition when it has lost 1% dry matter, the maximum storage time would be 4 months for long grain rice and 7 months for medium grain.

RECOMMENDATION FOR FUTURE STUDY

A continued effort must be made to minimize the experimental errors pointed out. An effort to maintain the moisture content throughout the test is strongly recommended.

It is suggested that sound and freshly harvested grain be used rather than material held in cold storage and requiring conditioning. It is also suggested to test the grain at safe storage moisture content for at least 6 months.

The relationship between carbon dioxide production and the quality of grain should be studied for other cereal grains, which should include short grain rice in the future tests.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to the major advisor Dr. Paul A. Seib, for his guidance, assistence and wisdom in completion of this study. The author would also like to express his sincere appreciation to the members of his graduate committee, Dr. Do Sup Chung and Dr. R. Carl Hoseney for their support and suggestions to finish this study.

Special thanks go to the author's former advisor, Dr. Harry B. Pfost for his guidance and unrelenting support and to Dr. Ulysses A. Acasio for his technical aid and assistance in doing this research.

Gratitude and appreciation to U.S.A.I.D. and the Indonesian Government for the financial support and opportunity in this study.

Finally the author wishes to express his deep gratitude to:

- Mrs. Rosemary Burroughs for support and technical assistance;
- Mr. Gangadhar R. Vemuganti and Dr. George A. Milliken for helpng in data analysis;
- Dr. Gerald Kline and Mr. Vergil Haynes and his staff for laboratory facilities and their technical assistance in doing the research.

The last, but the most important, this study would not have been finished without the support of his wife, Arum S. Sukabdi.

LITERATURE CITED

1. Brooker, D. B., Bakker-Arkema, F. W., and Hall, C. W. Drying Cereal Grains. Westport, Connecticut. The Avi Publishing Company, Inc. 1974.

2. Christensen, C. M., and Kaufmann, H. H. Microflora. In Christensen, C. M. eds. Storage of Cereal Grains and Their Products. St. Paul, Minnesota. American Association of Cereal Chemists. 1974.

3. Christensen, C. M., and Kaufmann, H. H. Grain Storage. The Role of Fungi in Quality Loss. University of Minnesota Press Minneapolis. 1969.

4. Drape, N. R. and Smith, H. Applied Regression Analysis. New York, London, Sydney. John Wiley & Sons, Inc. 1966.

5. Daniel, C., Wood, F. S. and Gorman, J. W. Fitting Equation to Data. Computer Analysis of Multifactor Data for Scientist and Engineers. New York, London, Sydney, Toronto. Wiley Interscience. A Division of John Wiley & Sons, Inc.

6. Foster, G. H. Minimum Airflow Requirements for Drying Grains with unheated air. Agricultural Engineering ; 681-684. 1953.

7 Hart, J. R., Feinstein, L., Golumbic, C. Oven method for precise measurement of moisture in seeds. Biological Science Division Ag. Marketing Service 1959. Marketing Research Report No. 304.

8. Henderson, S. M. and Perry, R. L. Agricultural Process Engineering. Third Edition. The Avi Publishing Company, Inc. Westport, Connectcut. 1976.

9. Hukill, W. V. Drying of grain. In Anderson, J. A. and Alcock, A. W. eds. Storage of Cereal Grains and Their Products. St. Paul, Minnesota, American Association of Cereal Chemists. 1954.

10. Hukill, W. V. Grain Drying. In Christensen, C. M. eds. Storage of Cereal Grains and Their Products. St. Paul, Minnesota, American Association of Cereal Chemists. 1974.

11. Hummel, B. C. W. Cuendet, L. S., Christensen, C. M. and Geddes, W. F. Grain Storage Studies XIII. Comparative Change in respiration, viability, and chemical composition of mold-free and mold-contaminated wheat upon storage. Paper No. 3052 of the Scientiffic Journal Series, Minnesota Agricultural Experiment Station. May 1952.

12. Karon, M. L. and Maybelle, E. A. S. Hygroscopic equilibrium of rice and rice fraction. Cereal Chem. 26: 1-12.

13. Kososki, A. R. Two Methods of Comparing Equilibrium Moisture of Grains. Unpublished M.S. Thesis. Kansas State University. 1977.

14. Milner, N. and Geddes, W. F. Respiration and Heating. In Anderson, J. A. and Alcock, A. W. eds. Storage of Cereal Grains and Their Products. pp. 152-220. St. Paul, Minnesota, American Association of Cereal Chemists. 1954.

15. Pfost, H. B., Maurer, S. G., Chung, D. S. and Milliken, G. A. Summarizing and Reporting Equilibrium Moisture Data for Grains. Paper No. 76-3520 presented at the 1976 Winter Meeting, December 14-17, Chicago, Illinois. 1976.

16. Pomeranz, Y. Biochemical, Functional, and Nutritive Changes During Storage. In Christensen, C. M. eds. Storage of Cereal Grain and Their Products. St. Paul, Minnesota, American Association of Cereal Chemists. 1974.

17. Saul, R. A. Biological Activity in Shelled Corn During Mechanical Drying. Unpublished M.S. Thesis. Iowa State University of Science and Technology, Ames, Iowa. 1960.

18. Saul, R. A. and Lind, E. F. Maximum Time for Safe Drying of Grain with unheated air. American Society of Agricultural Engineering Transactions 1: 29-33. 1958.

19. Schroeder, H. W. Drying, Storing and Handling Rice. Six Decades of Rice Research in Texas. Research Monograph 4, June, 1975.

20. Schroeder, H. W. and Calderwood, D. L. Rough Rice Storage. In Houston, D. F. eds. Rice Chemistry and Technology. St. Paul, Minnesota, American Association of Cereal Chemists. 1972.

21. Semeniuk, G. Microflora. In Anderson, J. A. and Alcock, A. W. eds. Storage of Cereal Grains and Their Products. St. Paul, Minnesota, American Association of Cereal Chemists. 1954.

22. Snedecor, G. W. and Cohran, W. G. Statistical Methods. Sixth Edition. The Iowa State University Press Ames, Iowa. 1967.

23. Steele, J. L. Deterioration of Shelled Corn During Drying as measured by Carbon Dioxide Production. Unpublished M.S. Thesis. Iowa State University of Science and Technology, Ames. 1963.

24. Steele, J. L. Deterioration of Damage Shelled Corn as measured by Carbon Dioxide Production. Unpublished Ph.D. Thesis. Iowa, State University of Science and Technology, Ames. 1967.

25. Steele, J. L., Saul, R. A. and Hukill, W. V. Deterioration of Shelled Corn as measured by Carbon Dioxide Production. Transactions of the ASAE. 12 : 685-689. 1969.

26. U.S. Department of Agriculture. Federal Grain Inspection Service. Inspection Handbook For The Sampling, Inspection, Grading and Certification of Rice. Washington D. C. U.S. Government Printing Effective March 1979.

27. Wasserman, T. and Calderwood, D. L. Rough Rice Drying in Rice Chemistry and Technology, Houston, D. F. eds. St. Paul, Minnesota, American Association of Cereal Chemists. 1972.

28. Webb, B. D. and Stermer, R. R. Criteria of Rice Quality. In Rice Chemistry and Technology, Houston, D. F. eds. St. Paul, Minnesota, American Association of Cereal Chemists. 1972.

APPENDIX

Table A-1. Calculated Equilibrium Relative Humidity (ERH) and selected temperature of saturating bottle for medium grain.

Box temperature °C	Initial Moisture %	Calculated ERH %	Saturating bottle temperature calculated °C	Saturating bottle temperature selected °C
35	22.40	98.4	34.7	35
35	20.70	96.8	34.5	35
35	18.33	93.8	34.2	33.9
35	15.27	84.6	31.8	32.2
29.5	22.40	98.3	29.0	29.5
29.5	20.70	96.6	28.6	29.5
29.5	18.33	93.3	28.1	28.3
29.5	15.27	83.3	26.4	26.7
24	22.40	98.1	23.6	23.3
24	20.70	96.3	23.2	23.3
24	18.33	92.7	22.4	22.8
24	15.15	82.0	20.6	21.1
18	22.40	97.9	17.8	18.1
18	20.70	95.9	17.5	18.1
18	18.33	92.0	15.8	17.2
18	15.27	80.3	14.7	15.6

Table A-2. Calculated Equilibrium Relative Humidity (ERH) and selected temperature of saturating bottle for long grain rice.

Box temperature °C	Initial Moisture %	Calculated ERH %	Saturating bottle temperature calculated °C	Saturating bottle temperature selected °C
35	22.25	98.0	34.7	35
35	20.50	97.0	34.7	35
35	17.90	93.0	34.3	33.9
35	15.15	85.6	32.2	32.2
29.5	22.25	98.0	29.2	29.5
29.5	20.50	97.0	28.9	29.5
29.5	17.90	93.0	28.2	28.3
29.5	15.15	84.4	26.2	26.7
24	22.25	98.0	23.6	23.3
24	20.50	96.4	23.2	23.3
24	17.90	92.0	22.5	22.8
24	15.15	83.0	20.8	21.1
18	22.25	98.0	18.1	18.1
18	20.50	96.0	17.5	18.1
18	17.90	91.0	16.7	17.2
18	15.15	81.5	15.0	15.6

Table A-3. Assigned sample numbers for experiment I.

Moisture content %	Temperature, °C 35	29.5	24	18
	Medium grain			
22.40	13 M	13 M	13 M	13 M
22.40	16 M	16 M	16 M	16 M
22.40	19 M	19 M	19 M	19 M
22.40	22 M	22 M	22 M	22 M
20.70	14 M	14 M	14 M	14 M
20.70	17 M	17 M	17 M	17 M
20.70	20 M	20 M	20 M	20 M
20.70	23 M	23 M	23 M	23 M
18.33	13 M	15 M	13 M	13 M
18.33	16 M	18 M	16 M	16 M
18.33	19 M	21 M	19 M	19 M
18.33	22 M	24 M	22 M	22 M
15.27	15 M	15 M	15 M	15 M
15.27	18 M	18 M	18 M	18 M
15.27	21 M	21 M	21 M	21 M
15.27	24 M	24 M	24 M	24 M
	Long grain			
22.25	25 L	25 L	25 L	25 L
22.25	28 L	28 L	28 L	28 L
22.25	31 L	31 L	31 L	31 L
22.25	34 L	34 L	34 L	34 L
20.50	26 L	26 L	26 L	26 L
20.50	29 L	29 L	29 L	29 L
20.50	32 L	32 L	32 L	32 L
20.50	35 L	35 L	35 L	35 L
17.90	25 L	27 L	25 L	25 L
17.90	28 L	30 L	28 L	28 L
17.90	31 L	33 L	31 L	31 L
17.90	34 L	36 L	34 L	34 L
15.15	27 L	27 L	27 L	27 L
15.15	30 L	30 L	30 L	30 L
15.15	33 L	33 L	33 L	33 L
15.15	36 L	36 L	36 L	36 L

Table B-1. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 35°C (95°F) and 21.07% moisture content.

	Sample Replicates				
Time h.	No.13M	No.16M	No.19M	No.22M	Mean CO_2
18	2.83	1.50	1.32	3.19	2.21
48	6.88	5.52	5.33	7.15	6.22
69	7.20	7.73	7.54	9.21	8.42
90	10.97	9.61	9.45	11.17	10.30
116	12.50	10.99	10.84	12.59	11.73
142	13.55	12.33	12.25	13.95	13.02
163	14.85	13.45	13.32	15.02	14.16
192	16.90	15.25	14.99	16.78	15.98
214	17.83	16.02	15.97	17.62	16.86
232	18.89	17.50	17.32	19.09	18.20
256	19.91	18.37	18.35	20.05	19.17
286	20.87	19.55	19.41	21.13	20.24
330	21.76	20.36	20.24	21.92	21.07
359	22.48	21.32	21.23	23.01	22.01
404	24.30	22.12	22.87	23.58	23.23
428	25.11	22.42	23.24	23.91	23.67

Table B-2. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 35°C (95°F) and 19.83% moisture content.

Time h.	Sample Replicates No.14M	No.17M	No.20M	No.23M	Mean CO_2
19	3.43	3.17	2.37	4.07	3.26
49	5.00	4.65	3.86	5.53	4.76
70	6.66	6.47	5.72	7.31	6.54
118	8.61	8.48	7.75	9.32	8.54
142	9.57	9.32	8.67	10.24	9.45
164	10.96	10.67	9.95	11.58	10.79
192	12.09	11.57	10.91	12.59	11.79
214	13.06	12.56	11.90	13.56	12.77
232	14.00	13.52	12.87	14.53	13.73
257	14.63	14.51	13.85	15.45	14.61
286	15.78	15.62	14.92	16.52	15.71
306	16.54	16.32	15.65	17.25	16.44
330	17.70	17.23	16.67	18.24	17.46
359	18.78	18.40	17.81	19.41	18.60
404	19.97	19.51	18.92	20.52	19.73
428	21.69	21.11	20.58	22.18	21.39
474	22.68	22.43	21.73	23.32	22.54
524	24.78	24.25	23.67	25.26	24.49
571	25.04	24.82	24.12	26.02	25.00
620	25.72	25.47	24.81	26.48	25.62
643	26.30	25.72	25.02	26.76	25.95
694	26.92	26.31	25.67	27.34	26.56
738	27.97	27.52	26.91	28.56	27.74
786	28.69	28.21	27.51	29.27	28.42
834	29.39	29.31	28.62	30.32	29.41

Table B-3. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 35°C (95°F) and 17.62% moisture content.

Time h.	Sample Replicates No.13M	No.16M	No.19M	No.22M	Mean CO_2
44	1.27	0.65	0.53	3.31	1.44
78	2.07	1.52	1.43	4.22	2.31
119	4.51	3.71	3.67	6.47	4.59
165	5.10	4.35	4.42	7.13	5.25
210	5.73	4.95	4.97	7.71	5.84
260	6.78	6.31	6.30	9.01	7.10
308	7.46	6.91	6.82	9.57	7.69
357	8.65	8.02	7.93	10.72	8.83
425	9.40	8.83	8.78	11.51	9.63
475	10.24	9.62	9.63	12.31	10.45
524	10.93	10.32	10.25	13.02	11.13
571	11.70	10.88	10.91	13.59	11.77
619	11.93	11.35	11.31	14.05	12.16
644	12.35	11.76	11.75	14.42	12.57
696	13.04	12.44	12.43	15.13	13.26
740	13.63	12.91	12.92	15.62	13.77
787	14.78	14.05	13.98	16.71	14.88
835	15.05	14.41	14.35	17.15	15.24
920	15.23	15.01	15.07	17.61	15.73
984	16.62	15.82	16.48	18.12	16.76

Table B-4. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 35°C (95°F) and 14.67% moisture content.

	Sample Replicates				
Time h.	No.15M	No.18M	No.21M	No.24M	Mean CO_2
43	0.44	0.24	1.02	0.82	0.63
88	0.59	0.38	1.76	1.55	1.07
119	0.62	0.41	2.47	2.26	1.44
166	0.87	0.66	2.54	2.33	1.60
210	1.20	0.99	2.93	2.72	1.96
261	1.31	1.10	3.16	2.95	2.13
308	2.05	1.84	3.72	3.51	2.78
362	2.73	2.52	4.16	3.95	3.34
424	3.06	2.85	4.59	4.38	3.72
474	3.19	2.98	4.70	4.49	3.84
521	3.38	3.17	4.91	4.70	4.04
568	3.76	3.55	5.33	5.12	4.44
617	3.91	3.70	5.44	5.23	4.57
695	4.00	3.79	5.61	5.40	4.70
739	4.34	4.13	5.99	5.78	5.06
786	4.49	4.28	6.18	5.97	5.23
835	5.03	4.82	6.70	6.49	5.76
904	5.28	5.07	7.01	6.80	6.04
982	6.79	5.98	7.62	7.25	6.91

Table B-5. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 29.5°C (85°F) and 21.74% moisture content.

Time h.	Sample Replicates No.13M	No.16M	No.19M	No.22M	Mean CO_2
25	2.83	2.80	3.67	4.30	3.40
51	5.02	3.91	4.92	5.67	4.88
71	6.49	4.82	6.71	7.42	6.36
97	8.57	7.81	8.74	9.40	8.63
116	10.78	10.21	11.32	12.01	11.08
143	13.73	12.62	13.63	14.30	13.57
164	14.94	13.94	14.95	15.65	14.87
193	15.99	15.55	16.63	17.27	16.36
215	18.05	17.50	18.71	19.34	18.40
233	19.92	18.97	20.02	20.81	19.93
259	20.82	19.98	21.05	21.75	20.90
287	21.76	21.43	22.51	23.10	22.20
354	23.44	22.83	23.92	24.65	23.71
408	24.67	24.15	25.27	25.91	25.00
429	25.46	24.65	25.71	26.30	25.53

Table B-6. Carbon dioxide (g/kg Of dry matter) produced by medium grain rice at 29.5°C (85°F) and 20.12% moisture content.

Time h.	Sample Replicates No.14M	No.17M	No.20M	No.23M	Mean CO_2
26	0.54	2.87	2.12	2.31	1.96
52	2.26	4.22	3.58	3.70	3.44
71	3.03	5.02	4.31	4.40	4.19
119	4.64	6.75	6.05	6.12	5.89
164	6.39	8.20	7.54	7.67	7.45
210	7.56	8.98	8.40	9.10	8.51
234	9.09	10.77	10.51	10.83	10.30
259	10.18	10.98	11.13	11.35	10.91
287	10.60	12.65	12.31	12.52	12.02
307	11.56	13.53	12.97	13.26	12.83
331	12.45	14.41	13.96	14.14	13.74
356	13.02	15.30	14.80	14.92	14.51
408	14.25	15.94	15.52	15.85	15.39
429	15.44	17.25	16.71	16.92	16.58
474	16.39	18.80	18.25	18.60	18.01
526	17.96	19.92	19.41	19.63	19.23
552	18.82	21.13	20.73	20.48	20.29

Table B-7. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 29.5°C (85°F) and 17.74% moisture content.

	Sample Replicates				
Time h.	No.15M	No.18M	No.21M	No.24M	Mean CO_2
18	0.78	0.76	1.03	1.27	0.96
42	1.28	1.23	1.58	1.65	1.46
92	3.39	1.32	2.72	2.73	2.54
119	3.81	1.75	3.08	3.24	2.97
140	4.09	2.22	3.61	3.72	3.41
162	4.90	2.72	3.90	3.96	3.87
189	4.96	3.06	4.35	4.51	4.22
213	5.02	3.12	4.51	4.63	4.32
234	5.19	3.26	4.69	4.74	4.47
261	6.17	3.97	5.24	5.38	5.19
308	6.85	4.56	5.80	5.91	5.78
356	6.91	4.88	6.17	6.28	6.06
404	7.34	5.35	6.64	6.71	6.51
450	8.11	6.11	7.43	7.51	7.29
499	8.19	6.18	7.48	7.59	7.36
545	8.82	6.63	7.92	8.07	7.86
618	9.78	7.64	8.93	9.05	8.85
669	10.35	8.11	9.47	9.51	9.36
712	10.66	8.41	9.72	9.89	9.67
937	11.32	9.12	9.87	10.75	10.29
984	12.07	9.94	11.21	11.46	11.17

Table B-8. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 29.5°C (85°F) and 14.96% moisture content.

Time h.	Sample Replicates No.15M	No.18M	No.21M	No.24M	Mean CO_2
21	0.13	0.12	0.16	0.19	0.15
45	0.25	0.25	0.31	0.35	0.29
95	0.68	0.63	0.82	0.91	0.76
121	0.78	0.97	1.18	1.23	1.04
165	1.43	1.32	1.57	1.64	1.49
191	1.58	1.48	1.62	1.72	1.60
216	1.79	1.56	1.82	1.95	1.78
290	1.86	1.90	2.19	2.33	2.07
357	1.93	2.07	2.38	2.54	2.23
406	2.60	2.38	2.62	2.76	2.59
452	2.88	2.75	3.04	3.25	2.98
501	2.92	2.98	3.25	3.37	3.13
547	3.21	3.06	3.42	3.59	3.37
621	3.37	3.44	3.63	3.88	3.54
672	3.56	3.71	4.12	4.29	3.92
715	3.84	4.19	4.19	4.36	4.07
937	4.20	4.27	4.56	4.73	4.44
986	4.84	5.21	5.43	5.68	5.29
1032	5.92	6.17	6.48	6.71	6.32

Table B-9. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 24°C (75°F) and 22.37% moisture content.

Time h.	Sample Replicates No.13M	No.16M	No.19M	No.22M	Mean CO_2
25	3.39	1.42	2.71	3.20	2.68
51	5.09	3.23	4.75	5.21	4.57
72	6.92	5.07	6.56	6.37	6.23
118	9.93	8.05	9.54	9.64	9.29
164	12.81	10.97	12.47	12.39	12.16
209	14.17	12.31	13.73	13.99	13.55
233	14.96	13.22	14.81	15.21	14.55
260	16.32	14.43	15.91	16.18	15.71
286	17.34	15.65	16.99	17.30	16.82
307	18.62	16.79	18.14	18.41	17.99
335	20.36	18.50	19.92	20.30	19.77
360	21.48	19.63	20.98	21.47	20.89
428	23.93	22.04	23.54	23.57	23.27
473	24.54	22.72	24.16	24.38	23.95
576	27.59	24.71	25.47	25.95	25.93

Table B-10. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 24°C (75°F) and 20.44% moisture content.

Time h.	Sample Replicates No.14M	No.17M	No.20M	No.23M	Mean CO_2
26	1.43	2.39	0.67	1.63	1.53
88	4.05	4.97	3.38	4.48	4.22
119	4.82	5.78	4.09	4.95	4.91
165	6.54	7.36	5.72	6.86	6.62
210	7.56	8.47	6.75	7.86	7.66
233	7.72	8.61	7.01	8.22	7.89
260	8.31	9.22	7.52	8.87	8.48
286	8.74	9.63	7.93	9.10	8.85
308	9.43	10.38	8.69	9.54	9.51
336	9.78	10.82	9.25	10.27	10.03
361	10.31	11.20	9.67	10.74	10.48
408	11.64	12.57	10.88	11.99	11.77
429	11.93	12.89	11.27	12.55	12.16
474	12.89	13.78	12.19	13.18	13.01
521	13.77	14.65	13.03	14.19	13.91
569	14.35	15.29	13.62	14.78	14.51
616	14.87	15.76	14.21	15.24	15.02
642	15.11	16.02	14.37	15.46	15.24
694	16.01	16.91	15.26	16.34	16.13
739	16.47	17.38	15.72	16.99	16.64
786	17.32	18.26	16.56	17.50	17.41
835	17.49	18.42	16.81	17.72	17.61
888	18.61	19.51	17.82	19.22	18.79

Table B-11. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 24°C (75°F) and 18.49% moisture content.

Time h.	Sample Replicates No.13M	No.16M	No.19M	No.22M	Mean CO_2
22	0.64	0.62	0.81	0.97	0.76
46	1.02	0.98	1.34	1.42	1.19
97	1.63	1.53	1.81	2.07	1.76
123	2.72	1.68	3.93	3.03	2.84
147	3.05	1.99	4.25	3.43	3.18
166	3.11	2.09	4.36	3.56	3.28
192	3.34	2.21	4.49	3.72	3.44
218	3.41	2.34	4.68	3.93	3.59
238	3.67	2.55	4.83	4.11	3.79
291	4.15	3.07	5.46	4.84	4.38
315	4.33	3.21	5.65	4.93	4.53
357	5.12	4.08	6.37	5.31	5.22
407	5.41	4.37	6.56	6.02	5.59
453	5.87	4.73	7.15	6.53	6.07
500	6.29	4.98	7.57	6.64	6.37
549	6.53	5.42	7.74	6.83	6.63
624	7.58	6.43	8.76	7.87	7.66
673	8.03	6.96	9.25	8.44	8.17
716	8.39	7.28	9.67	8.90	8.56
938	9.04	7.87	10.28	9.45	9.16
984	10.34	8.74	11.72	10.64	10.36
1080	11.82	9.43	12.62	11.41	11.32

Table B-12. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 24°C (75°F) and 15.60% moisture content.

Time h.	Sample Replicates No.15M	No.18M	No.21M	No.24M	Mean CO_2
24	0.11	0.10	0.16	0.23	0.15
48	0.23	0.20	0.35	0.50	0.32
100	0.61	0.59	0.74	0.94	0.72
149	1.11	1.07	1.32	1.54	1.26
196	1.36	1.25	1.49	1.66	1.44
221	1.48	1.37	1.67	1.72	1.56
293	1.52	1.41	1.75	1.96	1.66
361	1.83	1.72	2.03	2.26	1.96
412	1.95	1.83	2.18	2.32	2.07
456	2.27	2.09	2.47	2.69	2.38
504	2.34	2.24	2.66	2.88	2.53
551	2.61	2.49	2.83	2.95	2.72
626	2.78	2.65	3.12	3.37	2.98
691	3.05	2.99	3.37	3.47	3.22
720	3.12	3.05	3.42	3.53	3.28
956	3.74	3.89	4.15	4.22	4.00
987	3.85	3.93	4.21	4.41	4.10
1037	3.98	4.04	4.25	4.49	4.19
1102	4.04	4.12	4.31	4.57	4.26
1185	4.22	4.23	4.47	4.72	4.41
1275	4.39	4.37	4.61	4.87	4.56
1347	4.77	4.56	4.91	5.16	4.85
1428	5.55	5.29	5.63	5.89	5.59
1523	5.90	5.53	5.92	6.17	5.68
1601	6.21	6.03	6.41	6.63	6.32
1677	6.76	6.64	7.02	7.22	6.91
1768	7.36	7.21	7.62	7.81	7.50
1842	8.33	8.09	8.43	8.67	8.38
1923	9.55	9.42	9.81	10.02	9.70

Table B-13. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 18°C (65°F) and 22.97% moisture content.

	Sample Replicates				
Time h.	No.13M	No.16M	No.19M	No.22M	Mean CO_2
28	2.13	3.58	2.21	2.32	2.56
76	5.45	6.81	5.37	5.49	5.78
122	7.65	9.14	7.82	7.91	8.13
168	9.31	10.96	9.72	9.81	9.95
213	10.80	12.51	11.26	11.35	11.48
236	11.73	13.31	11.91	12.05	12.25
265	12.40	14.23	12.89	12.92	13.11
289	13.78	15.41	14.05	14.16	14.35
311	13.91	15.51	14.12	14.22	14.44
339	14.85	16.42	15.08	15.17	15.38
361	16.03	17.65	16.13	16.23	16.51
427	17.21	19.16	17.87	17.92	18.04
477	18.47	20.26	18.95	19.04	19.18
526	21.30	23.17	21.88	21.97	22.08
572	23.22	24.92	23.59	23.75	23.87
621	24.15	26.14	24.86	24.93	25.02
645	24.81	26.52	25.28	25.31	25.48
698	24.97	26.83	25.53	25.67	25.75
719	25.56	27.41	26.01	26.22	26.30
741	26.11	27.82	26.56	26.63	26.78
792	26.62	28.32	26.99	27.19	27.28

Table B-14. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 18°C (65°F) and 21.23% moisture content.

Time h.	Sample Replicates No.14M	No.17M	No.20M	No.23M	Mean CO_2
29	1.92	1.17	1.43	1.08	1.40
76	4.52	1.92	3.15	2.89	3.12
169	7.13	4.26	5.50	5.03	5.48
213	7.81	5.19	6.35	6.01	6.34
265	9.03	6.35	7.59	7.15	7.53
289	9.30	6.71	7.87	7.56	7.86
339	10.36	7.73	8.94	8.49	8.88
362	10.64	8.20	9.41	9.03	9.32
428	11.64	9.23	10.34	10.07	10.32
477	12.64	10.14	11.29	11.01	11.27
526	13.29	10.73	11.91	11.63	11.89
573	14.10	11.68	12.83	12.59	12.80
622	14.58	12.19	13.30	13.01	13.27
645	15.14	12.64	13.81	13.53	13.78
698	15.84	13.59	14.71	14.42	14.64
741	16.22	13.71	14.84	14.63	14.85
789	17.38	14.89	15.98	15.71	15.99
840	17.63	15.27	16.41	16.09	16.35
906	18.70	16.38	17.51	17.21	17.45
932	18.82	16.41	17.62	17.35	17.55
957	19.19	16.89	18.01	17.83	17.98
980	19.30	17.09	18.12	18.01	18.13
1032	20.12	17.57	18.63	18.36	18.67

Table B-15. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 18°C (65°F) and 18.78% moisture content.

Time h.	Sample Replicates No.13M	No.16M	No.19M	No.22M	Mean CO_2
24	0.77	0.55	0.55	0.53	0.60
48	1.26	0.81	0.83	0.74	0.91
100	2.06	1.45	1.42	1.35	1.57
149	2.65	1.93	1.91	1.87	2.09
168	3.18	2.36	2.34	2.24	2.53
196	3.42	2.85	2.81	2.76	2.96
221	3.61	3.01	2.99	2.91	3.13
244	3.80	3.13	3.12	2.99	3.26
293	3.99	3.31	3.26	3.16	3.43
337	4.44	3.72	3.65	3.55	3.84
361	4.91	3.98	3.97	3.82	4.17
415	5.70	4.45	4.59	4.38	4.78
457	5.92	4.89	4.92	4.87	5.15
505	6.04	5.31	5.38	5.19	5.48
552	6.28	5.74	5.72	5.62	5.84
626	6.85	5.89	5.91	5.83	6.12
691	7.19	6.15	6.23	5.99	6.39
720	7.25	6.37	6.38	6.28	6.57
956	8.13	8.62	6.77	7.52	7.76
986	8.31	8.91	6.83	7.71	7.94
1032	8.55	9.01	6.92	7.88	8.09
1109	8.98	9.72	7.53	8.45	8.67
1182	9.84	10.81	8.62	9.53	9.70
1274	11.27	11.90	9.71	10.64	10.88
1345	13.17	13.82	11.82	12.35	12.79
1425	14.32	15.21	12.99	13.92	14.11
1520	16.56	17.20	14.97	15.95	16.17
1591	17.64	18.41	16.21	17.14	17.35
1674	18.19	18.95	16.82	17.76	17.93
1769	19.31	20.17	18.03	18.93	19.11
1845	20.69	21.50	19.31	20.22	20.43
1921	20.73	21.56	19.37	20.26	20.48
1993	21.27	22.10	19.91	20.80	21.02

Table B-16. Carbon dioxide (g/kg of dry matter) produced by medium grain rice at 18°C (65°F) and 15.80% moisture content.

Time h.	Sample Replicates No.15M	No.18M	No.21M	No.24M	Mean CO_2
18	0.18	0.14	0.10	0.10	0.13
42	0.43	0.22	0.16	0.23	0.26
92	0.78	0.61	0.51	0.50	0.60
119	0.93	0.73	0.62	0.60	0.72
140	1.05	0.79	0.67	0.65	0.79
188	1.59	1.16	1.04	1.05	1.21
234	1.70	1.21	1.12	1.13	1.31
308	2.09	1.30	1.18	1.19	1.44
356	2.20	1.44	1.35	1.37	1.59
405	2.25	1.60	1.63	1.52	1.75
450	2.33	1.72	1.71	1.60	1.84
499	2.39	1.79	1.78	1.65	1.90
545	2.46	2.09	1.98	1.87	2.10
618	3.09	2.41	2.18	2.16	2.46
670	3.19	2.53	2.21	2.20	2.53
712	3.29	2.61	2.31	2.31	2.63
930	3.46	2.92	2.74	2.76	2.97
986	3.76	3.20	2.96	2.84	3.19
1031	3.81	3.34	3.25	3.20	3.40
1107	4.09	3.50	3.48	3.41	3.62
1180	4.63	3.72	3.69	3.76	3.95
1273	5.16	4.39	4.46	4.35	4.59
1346	6.19	4.57	6.53	5.47	5.69
1424	6.91	5.25	7.29	6.23	6.42
1521	8.81	7.18	9.20	8.16	8.34
1592	9.78	7.50	9.79	8.73	8.95
1673	10.49	8.63	10.82	9.70	9.91
1768	12.12	10.37	12.41	11.38	11.57
1842	14.27	11.44	13.99	12.94	13.16
1920	15.49	13.53	15.71	14.67	14.85

Table B-17. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 35°C (95°F) and 21.48% moisture content.

Time h.	Sample Replicates No.25L	No.28L	No.31L	No.34L	Mean CO_2
25	4.24	2.34	2.65	3.89	3.28
51	8.08	6.27	6.54	7.75	7.16
71	10.93	9.05	9.37	10.57	9.98
97	14.08	12.32	12.67	13.81	13.22
116	17.46	15.61	15.90	17.11	16.52
143	21.02	19.22	19.53	20.71	20.12
164	22.38	20.54	20.82	22.06	21.45
187	23.45	21.56	21.84	23.07	22.48

Table B-18. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 35°C (95°F) and 19.82% moisture content.

Time h.	Sample Replicates No.26L	No.29L	No.32L	No.35L	Mean CO_2
26	2.49	0.87	1.07	2.29	1.68
52	4.62	2.83	3.12	4.35	3.73
72	6.49	4.65	4.96	6.18	5.57
119	10.82	9.02	9.30	10.50	9.91
164	14.41	12.63	12.95	14.17	13.54
210	17.20	15.37	15.63	16.88	16.27
234	18.68	16.72	17.05	18.27	17.68
259	19.87	18.34	18.05	19.54	18.95
287	20.74	19.04	19.31	20.51	19.90
307	21.47	19.74	20.04	21.23	20.62
331	22.27	20.56	20.85	22.04	21.43
355	23.06	21.14	21.45	22.67	22.08
408	24.31	22.51	22.83	24.03	23.42
429	25.39	22.93	23.25	24.67	24.06

Table B-19. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 35°C (95°F) and 17.44% moisture content.

	Sample Replicates				
Time h.	No.25L	No.28L	No.31L	No.34L	Mean CO_2
43	2.90	1.12	1.50	2.52	2.01
78	5.16	1.25	2.67	3.68	3.19
120	5.40	3.65	4.06	5.05	4.54
165	6.80	4.97	5.35	6.36	5.87
210	7.77	5.96	6.34	7.37	6.86
260	8.64	6.82	7.21	8.25	7.73
308	10.00	8.18	8.57	9.57	9.08
356	11.23	9.19	9.58	10.58	10.07
426	12.21	10.25	10.63	11.67	11.19
474	13.41	11.24	11.65	12.78	12.27
524	13.93	12.15	12.53	13.55	13.04
571	15.25	13.37	13.76	14.78	14.29
620	15.49	13.86	14.15	15.18	14.67
643	16.13	14.45	14.74	15.76	15.27
695	16.74	15.24	15.53	16.53	16.01
739	17.24	15.73	16.02	17.05	16.51
787	18.26	16.52	16.87	17.87	17.38
835	18.53	16.94	17.23	18.26	17.74
920	19.61	18.02	18.31	19.34	18.82
1008	20.96	19.31	19.63	20.66	20.14

Table B-20. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 35°C (95°F) and 14.47% moisture content.

	Sample Replicates				
Time h.	No.27L	No.30L	No.33L	No.36L	Mean CO_2
43	0.68	0.29	0.32	0.71	0.50
88	1.57	0.38	0.47	1.62	1.01
119	2.12	0.54	0.63	1.87	1.29
166	2.51	0.97	1.18	2.34	1.75
210	2.87	1.21	1.43	2.65	2.04
261	3.45	1.70	1.95	3.14	2.56
308	3.86	2.31	2.52	3.71	3.10
362	4.60	2.90	3.17	4.33	3.75
424	5.15	3.63	3.81	5.01	4.40
474	5.48	3.86	4.09	5.25	4.67
522	5.91	4.23	4.45	5.65	5.06
568	6.26	4.62	4.86	6.06	5.45
616	6.70	4.91	5.18	6.37	5.79
695	6.96	5.42	5.60	6.82	6.20
739	7.32	5.74	5.92	7.14	6.53
786	7.58	6.08	6.27	7.43	6.84
835	7.86	6.36	6.55	7.75	7.13
904	8.18	6.55	6.74	7.97	7.36
931	8.20	6.67	6.86	8.07	7.45
954	8.31	6.71	6.90	8.12	7.51
977	8.39	6.78	6.99	8.20	7.59

Table B-21. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 29.5°C (85°F) and 21.71% moisture content.

	Sample Replicates				
Time h.	No.25L	No.28L	No.31L	No.34L	Mean CO_2
18	3.79	1.45	1.92	3.20	2.59
50	7.53	5.27	5.75	6.97	6.38
69	9.41	7.34	7.83	9.06	8.41
91	14.35	12.27	12.76	13.94	13.33
116	17.29	15.08	15.54	16.73	16.16
141	19.07	17.21	17.70	18.82	18.20
163	20.43	18.15	18.62	19.88	19.27
186	21.55	19.46	19.93	21.14	20.52

Table B-22. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 29.5°C (85°F) and 20.10% moisture content.

Time h.	Sample Replicates No.26L	No.29L	No.32L	No.35L	Mean CO_2
25	2.34	0.67	0.94	2.17	1.53
88	7.74	6.06	6.32	7.52	6.91
119	9.47	7.78	8.05	9.22	8.63
165	12.37	10.67	10.96	12.28	11.57
210	13.75	12.06	12.35	13.64	12.95
233	15.04	13.43	13.72	15.01	14.30
260	16.12	14.42	14.71	16.03	15.32
286	16.94	15.16	15.45	16.77	16.08
307	17.19	15.50	15.83	17.12	16.41
361	19.60	17.92	18.23	19.53	18.82
408	20.84	19.08	19.37	20.67	19.99
429	21.40	21.71	21.03	22.30	21.61

Table B-23. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 29.5°C (85°F) and 17.37% moisture content.

Time h.	Sample Replicates No.27L	No.30L	No.33L	No.36L	Mean CO_2
18	0.36	0.11	0.13	0.36	0.24
42	0.83	0.48	0.52	0.77	0.65
93	2.24	0.78	0.97	1.93	1.48
119	2.77	1.34	1.53	2.52	2.04
141	3.33	1.97	2.16	3.14	2.65
163	4.15	2.75	2.92	3.90	3.43
189	5.06	3.69	3.87	4.86	4.37
212	5.77	4.46	4.64	5.65	5.13
234	6.47	5.21	5.32	6.36	5.84
262	7.37	5.87	6.06	6.98	6.57
308	7.99	6.54	6.73	7.74	7.25
356	9.12	7.61	7.84	8.83	8.35
403	9.89	8.42	8.63	9.62	9.14
449	10.44	9.05	9.24	10.27	9.75
500	10.93	9.64	9.82	10.81	10.30
545	11.57	10.16	10.34	11.37	10.86
618	12.60	11.24	11.43	12.41	11.92
670	13.06	11.73	11.92	12.93	12.41
712	13.45	12.09	12.28	13.26	12.77
913	15.71	14.21	14.45	15.47	14.96
994	16.06	14.70	14.93	15.95	15.41

Table B-24. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 29.5°C (85°F) and 15.02% moisture content.

	Sample Replicates				
Time h.	No.27L	No.30L	No.33L	No.36L	Mean CO_2
24	0.27	0.11	0.10	0.28	0.19
48	0.56	0.20	0.21	0.43	0.35
100	0.98	0.57	0.62	0.87	0.76
150	1.84	0.83	0.90	1.71	1.32
169	2.07	1.02	1.41	1.93	1.54
195	2.30	1.31	1.43	2.24	1.82
221	2.55	1.62	1.75	2.56	2.12
245	2.99	2.00	2.10	2.95	2.51
293	3.95	2.71	2.82	3.68	3.29
337	4.35	3.33	3.43	4.25	3.84
361	4.66	3.65	3.76	4.53	4.15
412	5.25	4.20	4.30	5.17	4.73
456	5.57	4.60	4.71	5.52	5.10
505	5.98	4.82	4.92	5.76	5.37
551	6.13	5.07	5.18	5.98	5.59
626	6.47	5.35	5.47	6.27	5.89
690	6.71	5.61	5.71	6.53	6.14
720	6.80	5.72	5.85	6.67	6.26
955	7.78	6.81	6.90	7.75	7.31
1032	8.29	7.28	7.36	8.19	7.78

Table B-25. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 24°C (75°F) and 22.14% moisture content.

Time h.	Sample Replicates No.25L	No.28L	No.31L	No.34L	Mean CO_2
25	3.53	1.96	2.28	3.27	2.76
51	6.70	5.12	5.40	6.42	5.91
72	8.47	6.85	7.17	8.15	7.66
95	11.06	9.55	9.84	10.83	10.32
118	14.44	12.82	13.11	14.15	13.63
164	18.41	16.83	17.10	18.10	17.61
187	19.75	18.24	18.53	19.52	19.01
210	21.05	19.33	19.62	20.56	20.14
265	22.97	21.41	21.70	22.72	22.20
290	24.29	22.72	23.03	24.04	23.52
311	25.45	23.93	24.21	25.21	24.70
339	26.14	24.66	24.95	25.97	25.43
362	27.25	25.65	25.96	26.98	26.46
428	29.75	28.17	28.45	29.47	28.96

Table B-26. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 24°C (75°F) and 20.40% moisture content.

	Sample Replicates				
Time h.	No.26L	No.29L	No.32L	No.35L	Mean CO_2
29	2.63	0.76	1.22	2.23	1.71
76	5.87	3.92	4.43	5.42	4.91
118	8.04	5.95	6.44	7.45	6.97
169	9.96	7.93	8.41	9.46	8.94
214	11.14	9.25	9.72	10.73	10.21
265	12.82	10.80	11.36	12.34	11.83
290	13.73	11.85	12.37	13.37	12.83
311	14.44	12.37	12.88	13.87	13.39
339	15.27	13.26	13.77	14.74	14.26
362	16.01	13.93	14.45	15.45	14.96
428	17.82	15.74	16.26	17.26	16.77
477	19.06	17.06	17.58	18.58	18.07
526	20.22	18.34	18.83	19.81	19.30
573	21.57	19.45	19.97	20.97	20.49
621	22.66	20.63	21.16	22.15	21.65
645	23.10	21.25	21.75	22.74	22.21
698	24.62	22.41	22.92	23.97	23.48
719	25.04	23.02	23.51	24.55	24.03

Table B-27. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 24°C (75°F) and 18.35% moisture content.

Time h.	Sample Replicates No.25L	No.28L	No.31L	No.34L	Mean CO_2
22	0.74	0.62	0.55	0.93	0.71
46	1.95	0.99	1.07	2.03	1.51
97	3.32	2.17	2.26	3.21	2.74
123	3.49	2.43	2.51	3.57	3.00
147	3.94	2.97	3.02	4.07	3.50
167	4.41	3.18	3.27	4.30	3.79
193	4.53	3.77	4.08	4.78	4.29
219	4.95	4.62	4.70	5.41	4.92
239	5.25	4.91	5.04	5.72	5.23
291	6.29	5.93	6.07	6.75	6.26
315	6.96	6.72	6.81	7.51	7.00
356	7.46	7.15	7.26	7.93	7.45
409	8.76	8.35	8.47	9.18	8.69
453	9.67	9.37	9.45	10.15	9.66
500	10.49	10.15	10.28	10.96	10.47
548	11.07	10.82	10.91	11.60	11.10
622	12.80	11.63	11.73	12.72	12.22
673	13.49	12.33	12.42	13.40	12.91
716	14.04	12.71	12.83	13.82	13.35
938	16.02	14.75	14.89	15.92	15.41
994	17.34	16.02	16.17	17.19	16.68
1080	19.21	17.93	18.06	19.08	18.57

Table B-28. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 24°C (75°F) and 15.47% moisture content.

Time h.	Sample Replicates No.27L	No.30L	No.33L	No.36L	Mean CO_2
18	0.13	0.12	0.10	0.25	0.15
42	0.19	0.21	0.17	0.31	0.22
93	0.64	0.57	0.54	0.73	0.62
119	0.81	0.78	0.75	0.94	0.82
140	1.10	0.85	0.83	1.34	1.03
163	1.59	0.99	1.06	1.76	1.35
189	2.24	1.12	1.39	1.97	1.68
213	2.53	1.45	1.65	2.25	1.97
235	2.79	1.76	1.95	2.54	2.26
262	3.05	2.17	2.35	2.95	2.63
356	4.24	3.17	3.37	3.94	3.68
403	4.45	3.53	3.71	4.31	4.00
440	4.92	3.71	3.92	4.57	4.28
500	5.04	3.95	4.19	4.82	4.50
545	5.18	4.16	4.34	4.92	4.65
618	5.53	4.40	4.63	5.24	4.95
670	5.89	4.92	5.13	5.70	5.41
712	6.14	5.05	5.27	5.82	5.57
931	6.45	5.53	5.72	6.34	6.01
986	7.06	5.61	5.83	6.58	6.27
1033	7.42	6.23	6.44	7.07	6.79
1107	7.83	6.71	6.93	7.57	7.26
1188	8.13	7.02	7.21	7.88	7.56
1276	8.54	7.42	7.66	8.26	7.97
1348	8.70	7.73	7.94	8.55	8.23
1429	9.14	8.13	8.31	8.94	8.63
1512	9.38	8.33	8.52	9.17	8.85

Table B-29. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 18°C (65°F) and 23.04% moisture content.

Time h.	Sample Replicates No.25L	No.28L	No.31L	No.34L	Mean CO_2
28	3.12	3.88	1.45	3.47	2.98
75	6.97	8.93	7.56	8.46	7.98
123	11.15	13.35	11.83	12.87	12.30
168	14.89	16.82	15.36	16.33	15.85
213	16.54	18.63	17.11	18.12	17.60
236	17.60	19.60	18.10	19.10	18.60
264	18.41	20.25	18.72	19.78	19.29
289	19.36	21.25	20.03	21.16	20.55
311	20.97	22.65	21.26	22.28	21.79
339	22.54	24.50	23.05	24.07	23.54
361	23.89	25.86	24.30	25.39	24.86
427	27.39	29.03	27.63	28.67	28.18

Table B-30. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 18°C (65°F) and 21.05% moisture content.

	Sample Replicates				
Time h.	No.26L	No.29L	No.32L	No.35L	Mean CO_2
18	0.43	0.99	0.53	0.93	0.72
50	2.18	3.51	2.65	3.02	2.84
70	3.88	5.20	4.30	4.74	4.53
119	5.14	6.57	5.63	6.06	5.85
142	6.14	7.84	6.92	7.35	7.13
163	6.85	8.33	7.41	7.81	7.60
192	8.02	9.43	8.52	8.95	8.73
214	9.36	10.56	9.81	10.27	10.00
257	11.52	12.81	11.92	12.39	12.16
286	12.65	13.93	13.02	13.48	13.27
330	14.14	15.41	14.54	14.95	14.76
360	15.29	16.54	15.66	16.07	15.89
404	16.21	17.73	16.82	17.28	17.01
428	17.01	18.51	17.63	18.05	17.80
473	18.22	19.72	18.81	19.29	19.01
524	19.64	21.12	20.21	20.63	20.40
571	20.68	22.10	21.20	21.62	21.40
620	21.84	23.23	22.31	22.74	22.53
643	22.06	23.42	22.52	22.96	22.74
695	22.70	24.04	23.13	23.57	23.36
739	23.16	24.31	23.42	23.83	23.68
786	24.09	25.32	24.43	24.84	24.67
834	24.29	25.62	24.76	25.13	24.95
882	24.74	26.10	25.11	25.61	25.39

Table B-31. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 18°C (65°F) and 18.68% moisture content.

Time h.	Sample Replicates No.25L	No.28L	No.31L	No.34L	Mean CO_2
24	0.39	0.80	0.34	0.71	0.56
48	0.93	1.65	0.97	1.57	1.28
100	2.12	2.85	2.16	2.79	2.48
150	2.48	3.54	2.43	3.43	2.97
169	2.54	3.67	2.72	3.59	3.13
195	3.03	3.93	3.15	3.81	3.48
221	3.15	4.81	3.32	4.72	4.00
245	4.01	5.16	3.71	5.04	4.48
293	4.59	5.80	4.70	5.71	5.20
337	5.54	6.84	5.70	6.72	6.20
361	6.24	7.64	6.14	7.54	6.89
412	7.04	8.25	7.40	8.11	7.70
456	8.19	9.56	8.23	9.42	8.85
505	8.82	9.95	8.84	9.83	9.36
551	9.74	10.83	9.76	10.71	10.26
626	10.44	11.76	10.47	11.65	11.08
690	11.08	12.38	11.21	12.25	11.73
720	11.18	12.67	11.35	12.56	11.94
955	12.77	13.90	12.65	13.84	13.29
986	13.46	14.58	13.35	14.57	13.99
1032	13.83	14.98	13.77	14.98	14.39
1109	14.16	15.06	14.03	15.23	14.62
1182	14.38	15.45	14.27	15.46	14.89
1274	14.86	15.98	14.75	15.97	15.39
1345	15.75	16.63	15.60	16.82	16.20
1425	16.17	17.12	16.08	17.27	16.66
1520	16.95	17.95	16.84	18.06	17.45
1591	17.54	18.44	17.43	18.67	18.02
1674	18.14	19.04	18.05	19.25	18.62
1769	18.76	19.34	18.65	19.73	19.12
1845	19.46	20.37	19.34	20.55	19.93
1921	19.78	20.85	19.67	20.86	20.29
1993	20.26	21.17	20.15	21.34	20.73

Table B-32. Carbon dioxide (g/kg of dry matter) produced by long grain rice at 18°C (65°F) and 15.92% moisture content.

Time h.	Sample Replicates No.27L	No.30L	No.33L	No.36L	Mean CO_2
21	0.13	0.07	0.19	0.21	0.15
45	0.38	0.15	0.31	0.32	0.29
95	0.76	0.43	0.78	0.75	0.68
122	0.80	0.52	0.84	1.56	0.93
143	1.05	0.74	1.12	1.61	1.13
165	1.27	0.82	1.52	2.03	1.41
191	1.48	0.94	1.97	2.25	1.66
216	1.80	1.03	2.15	2.78	1.94
237	2.11	1.37	2.51	2.93	2.23
290	2.56	1.76	2.92	3.24	2.62
311	2.64	1.84	3.02	3.42	2.73
357	3.05	2.25	3.32	3.82	3.11
406	3.17	2.33	3.48	4.02	3.25
452	3.68	2.81	4.00	4.43	3.73
501	3.87	3.02	4.22	4.65	3.94
548	4.20	3.44	4.88	4.96	4.37
621	4.36	3.62	4.92	5.10	4.50
672	4.57	3.84	5.04	5.35	4.70
715	4.62	3.91	5.14	5.57	4.81
937	4.73	5.49	6.04	6.54	5.70
986	4.81	5.61	6.27	6.67	5.84
1031	5.38	5.83	6.44	6.83	6.12
1105	5.75	6.06	6.65	7.06	6.38
1183	6.10	6.47	7.06	7.45	6.77
1275	7.27	7.53	8.19	8.57	7.89
1346	7.92	8.24	8.85	9.23	8.56
1427	8.63	9.02	9.63	10.04	9.33
1521	9.64	10.07	10.46	10.87	10.26
1592	10.15	10.48	11.07	11.46	10.79
1673	11.19	11.55	12.19	12.59	11.88
1768	12.25	12.73	13.34	13.72	13.01
1842	13.37	13.68	14.26	14.65	13.99
1896	13.99	14.02	14.61	15.02	14.41

Table C-1. Statistical analysis of the dry matter loss model for long grain rough rice.

KSU-DML-MODEL

$$DML = 1 - EXP\left[-(A \times t^{C}) \times EXP\left\{D \times (T-60)\right\} \times EXP\left\{E \times (W-0.14)\right\}\right]$$

Name	Coefficients	Standard Error	T value	95% Confidence limits Lower	Upper
A	0.001889	0.0000439	43.0	0.0018	0.00197
C	0.710096	0.00896	79.3	0.693	0.728
D	0.027399	0.000498	55.0	0.0264	0.0284
E	31.6219	0.318	99.5	31.0	32.2

No. of observations	277
No. of coefficients	4
Resdual degrees of freedom	273
Residual root mean square	0.00059743
Residual mean square	0.00000036
Residual sum of square	0.00009744

Table C-2. Statistical analysis of the dry matter loss model for medium grain rough rice.

KSU-DML-MODEL

$$DML = 1 - EXP\left[-(A \times t^{C}) \times EXP\left\{D \times (T-60)\right\} \times EXP\left\{E \times (W-0.14)\right\}\right]$$

Name	Coefficients	Standard Error	T value	95% Confidence limits Lower	Upper
A	0.000914	0.000019	48.7	0.000878	0.000951
C	0.653966	0.00536	122.0	0.643	0.664
D	0.037568	0.000313	120.1	0.037	0.0382
E	33.6102	0.235	142.8	33.1	34.1

No. of observation	296
No. of coefficients	4
Residual degrees of freedom	292
Residual root mean square	0.00038556
Residual mean square	0.00000015
Residual sum of square	0.00004341

Table C-3. Statistical analysis of the dry matter loss model for pooled medium and long grain rough rice.

KSU-DML-MODEL

$$DML = 1 - EXP\left[-(A \times t^{C}) \times EXP\{D \times (T-60)\} \times EXP\{E \times (W-0.14)\}\right]$$

Name	Coefficients	Standard Error	T value	95% Confidence limits Lower	Upper
A	0.001601	0.0000696	23.0	0.00146	0.00174
C	0.608059	0.0137	44.4	0.581	0.635
D	0.029386	0.000798	36.8	0.0278	0.0309
E	29.0079	0.523	55.4	28.0	30.0

No. of observation	573
No. of coefficients	4
Residual degrees of freedom	569
Residual root mean square	0.00145877
Residual mean square	0.00000213
Residual sum of square	0.00121084

APPENDIX D. STATISTICAL ANALYSIS OF DRY MATTER LOSS MODEL

The statistical analysis of dry matter loss model indicates a relatively low value of standard error of coefficients and high T-value.

The differences between the value of dry matter loss obtained from the experiment and the fitted value, known as residuals, are small if the model equation is correct. The usual assumptions are that the errors are independent, have zero mean, a constant variance, and follow a normal distribution. If the model is correct the residuals should not exhibit a denial assumption. The computer plot of the residuals versus their corresponding corresponding equation value will show whether there is dependence of the magnitude of the residual on the magnitude of the equation value. Fig. D-1 and D-2 show the cummulative distribution of residuals plotted on the cummulative normal grid. As the line is straight diagonal, the residuals are distributed normally and the model equation is termed an adequate representation of the data. Fig. D-3 and D-4 show the computer plot of residuals versus fitted Y which indicates that the residuals are evenly distributed and the variance of the points about the line is roughly constant. Another way of plotting the residuals is the time sequence plot. In Fig. D-5 and D-6 the residuals are plotted against increasing time. The impression of a horizontal "band" of residuals indicates that a short term time effect is not influencing the data, and the variance is constant with increasing time. The time effect in residuals indicates that the equation is adequately fitted to the value of the data.

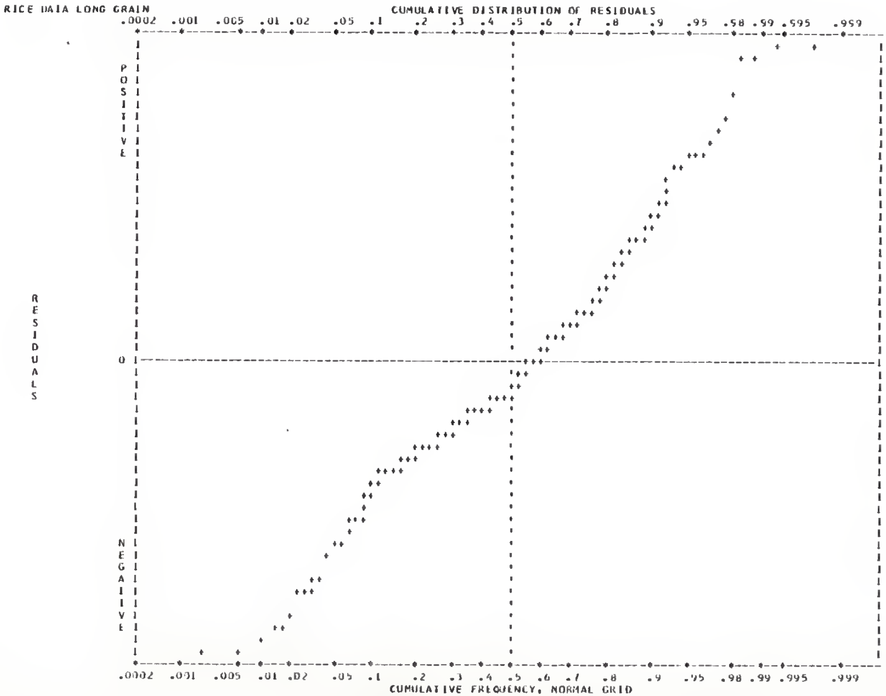


Fig. D-1. CUMULATIVE DISTRIBUTION OF RESIDUALS FOR LONG GRAIN RICE

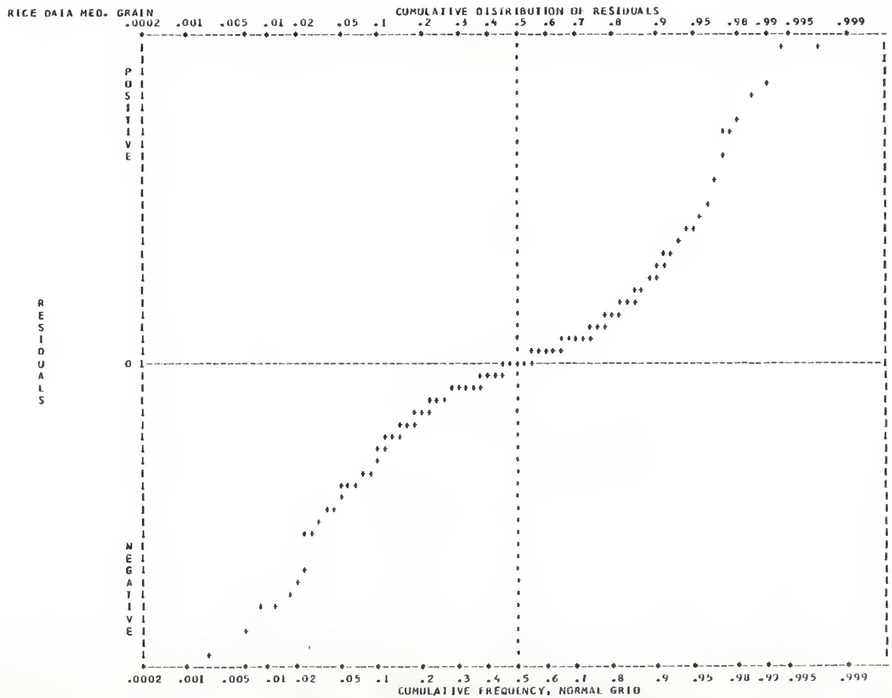


Fig. D-2. CUMULATIVE DISTRIBUTION OF RESIDUALS FOR MED. GRAIN RICE

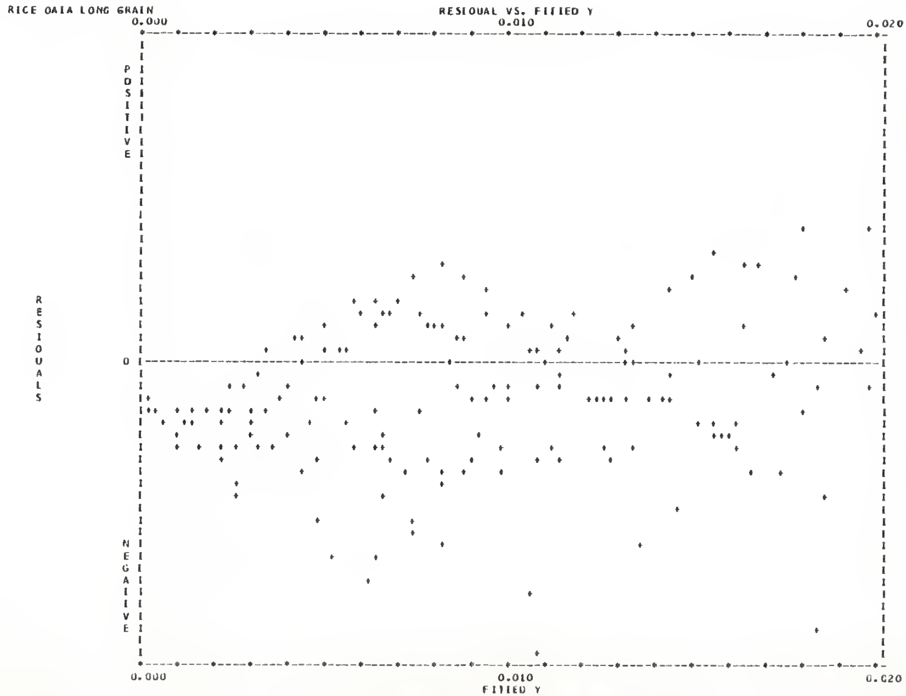


Fig. D-3. RESIDUAL VS. FITTED Y FOR LONG GRAIN RICE

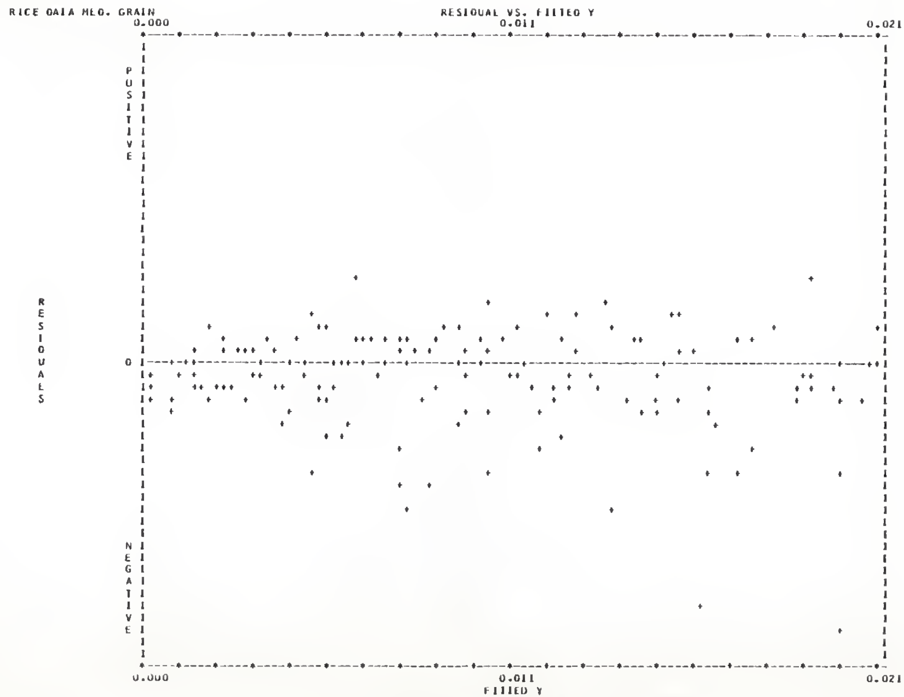
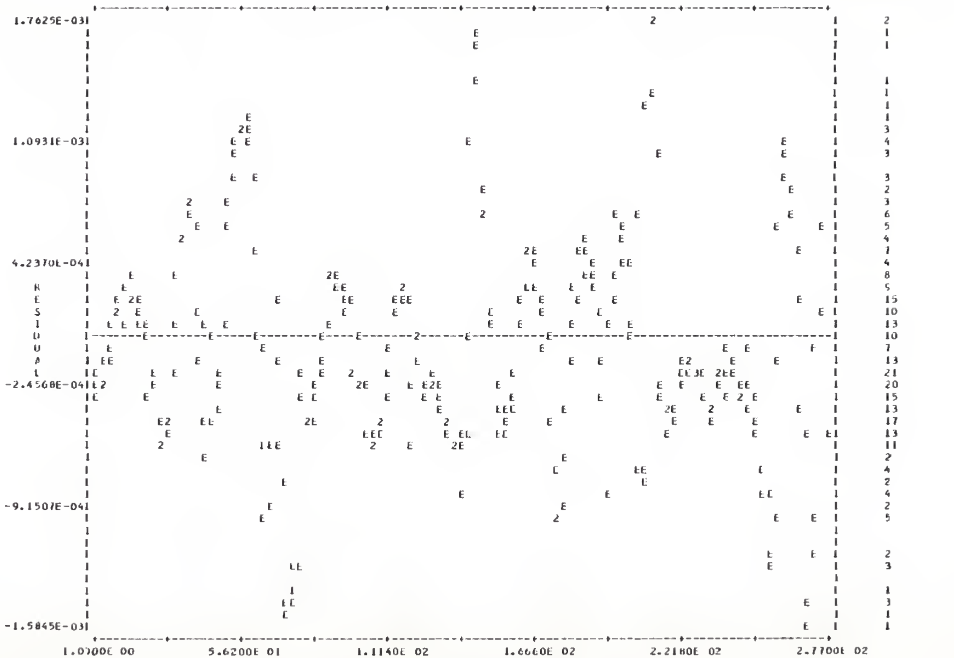


Fig. D-4. RESIDUAL VS. FITTED Y FOR MEDIUM GRAIN RICE

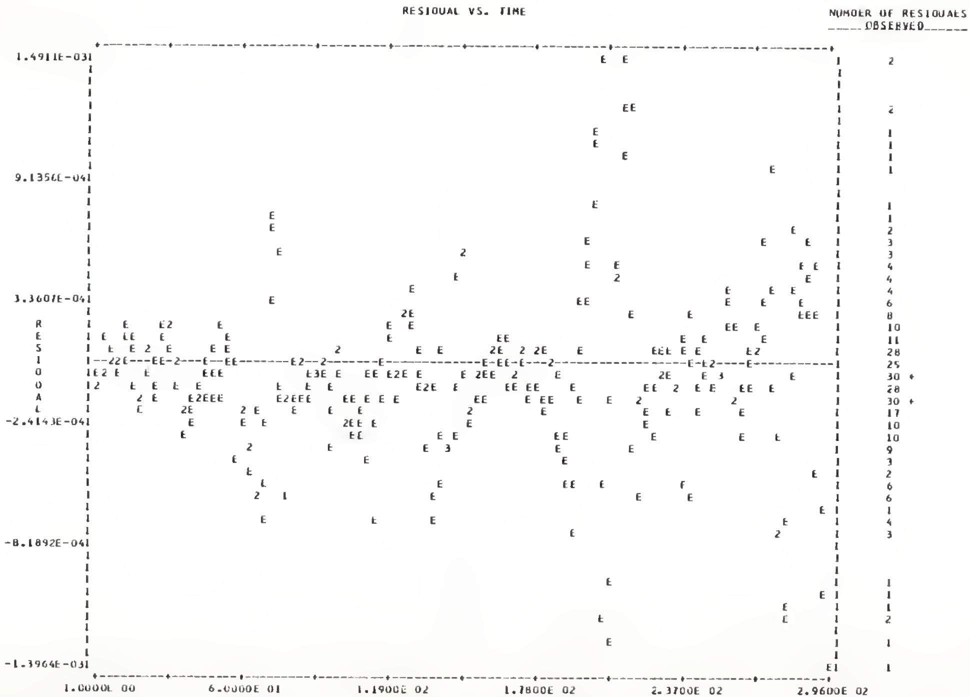
RESIDUAL VS. TIME

NUMBER OF RESIDUALS OBSERVED



END OF PROBLEM RICE DATA LONG GRAIN

Fig. D-5. RESIDUAL VS. TIME FOR LONG GRAIN RICE



END OF PROBLEM RICE DATA MED. GRAIN

Fig. D-6. RESIDUAL VS. TIME FOR MEDIUM GRAIN RICE

Table E. Variety differences for rough rice from KSU-DML-MODEL using the data experiment I

Variety	Degree of freedom	SSE
Medium	292	0.00004341 (SSE1)
Long	273	0.00009744 (SSE2)
Pooled Medium & Long	569	0.00121084 (SSE0)

H_o : Medium Grain = Long Grain

$$SSH_o = 0.00121084 - (0.00004341 + 0.00009744)$$
$$= 0.00121084 - 0.00014085$$
$$= 0.00106999$$

$$F_c(4,565) = \frac{0.00106999/4}{0.00014085/565} = \frac{0.0002674975}{0.0000002495} = 1072.134269$$

Reject H_o if $F_{0.99}(4,565) > 3.05$

Conclusion :

Medium grain is significantly different from long grain used in this study in dry matter loss.

DETERIORATION OF ROUGH RICE

AS MEASURED BY CARBON DIOXIDE PRODUCTION

by

AMIHARDJONO SUKABDI

B.S. Fakultas Tehnologi Pertanian Universitas Gajah Mada Indonesia

1967

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1979

ABSTRACT

The method of Steele, Saul and Hukill (Trans. of ths ASAE 12 : 685-689, No. 5, 1969) was used to follow the deterioration of rough rice during storage at four temperatures (18, 24, 29.5 and 35°C) and four moisture levels (15, 18, 21 and 23%). One variety of long grain rice and one variety of medium grain rice were studied in the 4 x 4 x 2 experimental design. In the laboratory-scale storage experiment, air was scrubbed free of carbon dioxide, conditioned to the proper relative humidity, passed through the grain, and the carbon dioxide released by the grain was followed with storage time. Each sample of grain was rsmovsd when its quality was judged to be lowered by invasion of destructive molds. Dry matter loss was calculated from CO_2 evolved, and ranged from 0.50 to 2.0% for all samples. The experimental curves showing dry matter loss with storage time are presented along with the regression lines and regression equation. In addition, data on milling yields and grades (U.S. Standard) are given for the samples storaed at 15 and 18% moisture.

In a separate experiment long grain rice, when stored at 29.5°C and 18% moisture, was allowed to lose dry matter to six different levels (0.25 to 2.0%). This experiment was also done on medium grain rice at 29.5°C and 23% moisture. The rice samples were milled and graded unofficially.